REPORT 408A

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AD661748

ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

64 RUE DE VARENNE, PARIS VII

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RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES

(WITH AN ADDENDUM CONTAINING COMMENTS ON THE RECOMMENDATIONS)

N65-28861

(ACCESSION NUMBER)	(THRU)
71 (PAGES)	3 (CODE)
(NASA CR OR TMX OR AD NUMBER)	02 (CATEGORY)

FACILITY FORM 602

OCTOBER 1964

DDC DEC 4 1967

NORTH ATLANTIC TREATY ORGANIZATION

71

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RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES
WITH AN ADDENDUM CONTAINING COMMENTS ON THE RECOMMENDATIONS

This Report is the outcome of a series of meetings held by the AGARD Flight Mechanics Panel Working Group on V/STOL Handling Qualities

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SUMMARY

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This Report presents the recommendations of a Working Group sponsored by the AGARD Flight Mechanics Panel, on desirable handling qualities for military V/STOL aircraft. The recommendations, which are necessarily tentative, particularly as regards their application to large aircraft, are based in some respects on requirements for U.S. military helicopters, but considerable use has been made of the results of flight assessments of handling qualities of a number of V/STOL research aircraft. To improve their validity, they should be kept under continual review by critical, systematic comparison with the accepted handling qualities of as many new V/STOL aircraft as possible.

An Addendum now included with the Report contains comments from various sources on the Recommendations.

Author

SOMMAIRE

Ce rapport présente les recommandations d'un Groupe de Travail de la Commission AGARD sur la Mécanique du Vol concernant les qualités de maniabilité à souhaiter dans les avions V/STOL militaires. Ces recommandations, nécessairement offertes à titre de suggestions seulement, lorsqu'il s'agit des avoins de gros tonnage, se basent à certains égards sur les spécifications établies pour les hélicoptères militaires américains, mais tiennent compte de façon importante des résultats d'évaluations en vol des qualités de maniabilité effectuées sur un certain nombre d'avions de recherche V/STOL. Pour en augmenter la justesse, il foudra que ces recommandations soient constamment passées en revue, en faisant une comparaison critique et systématique avec qualités de maniabilité acceptées du plus grand nombre possible des avions V/STOL de type nouveau.

Un Supplément maintenant compris contient quelques observations de sources diverses à propos les Recommandations.

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RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES

INTRODUCTION

1. BACKGROUND

The AGARD Flight Mechanics Panel Working Group on V/STOL Handling Qualities was set up in 1960 with the following terms of reference:

(a) To report to the Panel on the present status of handling qualities requirements relating to V/STOL aircraft in the member nations.

(b) To make recommendations on necessary research.

(c) Ultimately to make recommendations on handling qualities of particular interest to member nations in relation to NATO V/STOL projects.

The Group comprised one representative each from Canada, France, U.K. and U.S., with a Technical Secretary from the Netherlands. Item (a) above was accomplished by the Technical Secretary, following a tour of facilities in the member countries, in the Spring of 1961. The whole Group met on four occasions, as a result of which it was able to make recommendations for handling qualities (Item (c) above) for normal and emergency cases. These recommendations form the substance of the present report.

Early in 1962 a set of recommendations covering the normal (non-emergency) cases only had been distributed on a limited scale. A number of comments from Industry resulted from this. Others have arisen following the recent NATO evaluation of the NBMR-3 and NBMR-4 projects. Many of these comments have been embodied into the present document. Lack of time has prevented the Working Group from considering all the suggestions that have been received. Readers whose comments appear to have been ignored are asked to be patient, as doubtless a further revision will be necessary in due course.

2. APPLICABILITY OF THE RECOMMENDATIONS

It was hoped that the recommendations would, eventually, cover all forms of V/STOL aircraft including helicopters, with the addition of some specialised items. The present proposals fall short of this aim, as some purely-helicopter items (e.g. auto-rotation) have not been included.

These proposals refer only to the low-speed régime, i.e. that in which an appreciable proportion of the lift is derived from engine power. The upper limit of applicability is the Conversion Speed (V_{Con}), which is the speed at which the aircraft achieves a more-or-less conventional configuration. On a tilt-wing aircraft, it may be the speed at which wing tilt becomes zero; for a jet-lift aircraft, the speed may be that at which the lift engines are switched off, and/or the thrust vector is rotated to the propulsion position. For a helicopter, the recommendations would apply up to the maximum speed, since no conversion takes place. No more precise definition will be attempted, and it is assumed that V_{Con} would be chosen by the contractor.

Above V_{Con} , conventional flight requirements will apply. It is appreciated that a standard set of requirements for conventional flight does not yet exist in NATO, and it is recommended that steps be taken to remedy this deficiency.

3. THE NEED FOR REVIEW

It is quite obvious that, in the present state of the art, there is insufficient experience to be certain of the desirable level or even of the actual form of many of the individual items in the recommendations. Therefore, it is essential that they be subject to periodic review at intervals not exceeding, say, 1 year. Though this procedure is, of course, quite normal, it is especially important in the present context because of the likely rate at which new data and experience are expected to accumulate in the V/STOL field in the near future. It is certainly to be hoped that the progress of flight, wind tunnel and simulator work will be maintained at no less than the present rate.

Meanwhile, when specific suggestions are made for numerical handling qualities criteria, special care is needed in their application at this time because of the lack of experience (particularly in flight) against which the proposals can be judged. Some latitude may have to be associated with these items.

In particular the recommendations for control response and damping in pitch, roll and yaw are open to criticism. Account is taken only of changes in weight whereas, clearly, two aircraft of the same weight but of different configuration will respond differently to the same external disturbances. The proposed form of these recommendations, which is based on helicopter experience, is believed to be the best guide that can be given at present; and is preferable to a vague general requirement for 'satisfactory' controllability in the presence of a given external disturbance, and for the performance of manoeuvres necessary for the transition and for hovering.

There is thus an urgent need to improve the validity of these particular recommendations. Information from ground-based simulators and variable-stability aircraft is accumulating and must be properly correlated. An important aim must be to improve our understanding of the desirable relations between control sensitivity, damping and response to external disturbances. From this a better basis for the establishment of scaling factors for size and/or weight can be obtained, but the real need is for experience in VTOL aircraft significantly larger than those which have already flown.

One criticism of the earlier edition, which probably will still be applied to this one, is that the proposals tend too much towards being a designers' guide and do not sufficiently specify actual flying qualities. In fact, the proposals are a mixture of both; all are intended to be demonstrable in flight, but some are admittedly written so as to be of direct use to designers and need 'translation' for flight test purposes. However, the main aim is to specify what the pilot wants and it may be desirable in a future edition to divide the document into two parts, one of which is restricted to a statement of this aim, while the other suggests likely design standards which should ensure that it is satisfied.

4. INTERPRETATION

4.1 The Level of the Recommendations

The proposals for normal operation refer to all-weather, instrument flight conditions and are intended to define handling qualities which should result in satisfactory behaviour, though perhaps with some mildly unpleasant characteristics, as a minimum. (It is assumed that all necessary artificial aids are working satisfactorily.) This definition corresponds to a pilot opinion rating of better than 3½ on the NASA scale. For convenience the scale is reproduced at the end of this Introduction.

The emergency cases considered in the first five sections of the recommendations define the minimum acceptable handling qualities in the event of any single failure in either the power control system or the stability augmentation system, or in any other flight control system. It is furthermore assumed that the effects of any such failure are limited to either the longitudinal or the lateral-directional mode, but will not affect both at the same time. The level of behaviour is then expected to result in a pilot opinion rating of not worse than 6½ on the NASA scale.

Section 6 deals with the effects of engine failure on handling qualities. Such a failure on a single-engined aircraft must at least allow the pilot to escape. On a multi-engined aircraft continued flight is assumed to be possible, either to an immediate emergency landing, or to a normal landing. In either case trim changes should be limited as indicated. For a normal landing it can be assumed that the handling qualities could deteriorate to the level proposed as acceptable following a power control system or stability augmentation system failure. In the case of the immediate emergency landing some further deterioration in flying qualities would be acceptable.

No attempt has been made to define the thrust margins that should remain after engine failure as this is considered to be a design requirement, depending on the specified safety level for the aircraft.

4.2 Wind Conditions

Some recommendations are written in terms of a steady wind speed and direction, others depend more on the gust level. The gust level to be used should be specified in the design requirements for the particular aircraft. The ability to operate in a steady wind up to 35 knots from any direction would in many cases take care of the gust level experienced in a large proportion of actual wind conditions.

4.3 Simultaneous Use of Controls

The specified control power about any axis is the value which should be obtained, no matter how any other control may be used.

4.4 Weight and Inertia

The weight and corresponding moment of inertia used in the control response recommendations for a particular aircraft are those which are critical with respect to control power. At any other weight (and inertia) the response should therefore be better than the recommended figure.

5. TERMINOLOGY

The following definitions will be used throughout, in relation to control characteristics for trimming and manoeuvring:

(a) Sensitivity - the initial angular acceleration per unit step control displacement from any trim position.

(b) Response - the change in attitude in one second from the initiation of a control input.

(c) Damping Moment - the total moment resisting angular velocity.

(d) Control Power - ratio of control moment to moment of inertia about the appropriate axis, for full control displacement.

(e) Nominal Control Moment - one half of the total control moment change available between the control stops, at the given flight conditions.

(f) Control Effectiveness - capability of trimming and manoeuvring the aircraft throughout its design envelope.

(g) Control Displacement - the displacement of the pilot's control element in the cockpit.

6. FLIGHT INSTRUMENTATION AND CONTROL SYSTEMS

It is realized that the ease and accuracy with which a pilot can perform a given task, and hence his rating of the aircraft's handling qualities, depend on the quality of the instrument display at his disposal. For the present, instrumentation at least of the standard currently available has been assumed. When more specialized equipment for V/STOL operation becomes available some of the present proposals may possibly be changed.

The present recommendations have been written on the basis of conventional cockpit controls, i.e. stick or wheel plus rudder bar, with either a conventional throttle or a helicopter-type lever. However, it is not intended to exclude other control arrangements. Where a particular item would clearly need modification before application to an unconventional layout, this is indicated by a symbol * in the text.

7. CLASSIFICATION OF AIRCRAFT

Different recommendations for different classes of aircraft have been avoided, although it is fully realized that this can lead to severe design problems in some cases - e.g., on large aircraft. However, it must be pointed out that V/STOL operation calls for precise flying, and that even on the large aircraft all controls should be operable with forces appropriate to one hand, since the engine power control lever

will have attained the status of a primary flying control. Stick loads requiring two-handed operation would therefore be unacceptable.

Operational evaluation of aircraft against the standards recommended in this document will show whether a single set of requirements can successfully be applied to aircraft of widely-differing configurations.

8. RECOMMENDATIONS FOR RESEARCH

The subjects on which further research could most usefully be done at the present stage appear to be:

(1) Continued examination of the objectives of the pilot, to provide a more logical analysis of the required levels of control power, sensitivity, damping, etc., in the presence of disturbances and while manoeuvring.

(2) Scaling factors, which at present account only for differences in weight, but which should almost certainly account for differences in configuration, size, etc.

(3) Lift margins in STOL operation, which are intermediate between VTOL and conventional operations and appear to call for special consideration. No entirely satisfactory proposals exist at present.

(4) Manoeuvres and procedures involved in the operational use of V/STOL aircraft in restricted spaces and in all-weather conditions.

(5) Gust spectrum below 500ft, to assist in the solution of the above problems.

REFERENCES

The Group gratefully acknowledges the help it has received from the following papers:

1. Seth B. Anderson — *An Examination of Handling Qualities Criteria for V/STOL Aircraft.* NASA TN D-331, July 1960.

2. - — *General Specification for Helicopter Flying and Ground Handling Qualities.* MIL-H-8501A, Sept. 7, 1961.

3. - — *NASA Conference on V/STOL Aircraft - A Compilation of the Papers Presented.* November 17-18, 1960.

NASA Pilot Opinion Rating System

	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1	Excellent, includes optimum	yes	yes
		2	Good, pleasant to fly	yes	yes
		3	Satisfactory, but with some mildly unpleasant characteristics	yes	yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	yes	yes
		5	Unacceptable for normal operation	doubtful	yes
		6	Acceptable for emergency condition only	doubtful	yes
No operation	Unacceptable	7	Unacceptable even for emergency condition	no	doubtful
		8	Unacceptable - dangerous	no	no
		9	Unacceptable - uncontrollable	no	no
	Catastrophic	10	Motions possibly violent enough to prevent pilot escape	no	no

SECTION 1

CHARACTERISTICS OF THE CONTROL SYSTEM

1.1 GENERAL

It is important that the characteristics of the control system as felt by the pilot should not result in objectionable handling qualities at any speed or in any configuration covered by these recommendations. In particular, the effects of centring, breakout force, feel, pre-load, friction, free play, etc., should not result in objectionable flight characteristics or permit large departures from trim conditions with controls free. There should be no undesirable variations in the control force gradients of the longitudinal, lateral or directional controls.

In the case of any single failure in powered or boosted systems, artificial trim devices or stability augmentation systems it is important that the characteristics of the control system as felt by the pilot should not result in unacceptable flying qualities in the configurations and flight conditions appropriate to emergency operation.

1.2 BREAKOUT FORCES*

Breakout forces, including friction, feel, preload, etc. should be within the limits shown in the following Table. The forces should be those measured at the pilot's control in flight, or in conditions resembling those in flight as closely as possible. The forces apply to all aircraft, irrespective of size†, and for stick or wheel-type controls. The height control may be either a conventional throttle lever or a helicopter collective-pitch-type stick.

Control	*Normal operation (lb)*	*After failure of appropriate power control system (lb)*
Longitudinal	0.5 - 2.5	< 5
Lateral	0.5 - 2.0	< 4
Directional	1.0 - 10.0	< 15
Height — stick	1.0 - 3.0	< 5
— throttle	1.0 - 3.0	< 3

*Based on conventional cockpit controls. See also Section 6 of the Introduction.

†Further experience in the design and operation of large V/STOL aircraft may make some revision desirable. See also Section 3 of the Introduction.

1.3 CONTROL FORCE GRADIENTS AND GRADIENT CHARACTERISTICS*

For all controls, the slope of the control force versus displacement beyond the breakout region should be positive, with the slope for the first inch of displacement from trim equal to or greater than the slope for the remaining stick travel. In addition, the total force for the first inch of travel from trim should not be less than the breakout force. For VTOL operation, longitudinal and lateral control force gradients of between 1 and 2.5 lb/inch are desirable. For the directional control the gradient should be between 5 and 15 lb/inch. After a failure in a power control system the gradients should be no more than twice the above values.

With increasing forward speed a smooth transition to the gradients appropriate to conventional flight is desired. STOL operations therefore represent an intermediate case. A longitudinal control stick travel of about ± 4 inches, and a lateral and directional control travel of about ± 3 inches has been assumed throughout.

After a failure in a power control system, any manoeuvre within the design flight envelope should not require control forces exceeding 40 lb longitudinally, 20 lb laterally and 80 lb directionally.

1.4 CHARACTERISTICS OF HEIGHT CONTROL SYSTEMS

The height control should remain fixed at all times, unless moved by the pilot or some automatic system. Adjustable friction is desirable, but the limiting forces* specified in the table should be achieved with any friction damper off.

The recommendation should also be met following a failure in a power control or stability augmentation.

1.5 CHARACTERISTICS OF POWER CONTROL SYSTEMS

The mechanical characteristics of the control linkage (e.g. the free play and friction in the system) and of any associated hydraulic or other power control system incorporating a selector valve should be such as to ensure freedom from objectionable flight characteristics, including difficulty in trimming or tendency towards pilot-induced oscillations.

This recommendation should also be met following a failure in a power control or stability augmentation system.

1.6 FREE PLAY

The free play in each cockpit control, i.e. the motion of the cockpit control from the trim position which does not move the control surface or produce any response of the aircraft in flight, should neither cause objectionable handling characteristics nor in any case exceed ± 1 per cent of total travel. Following a failure in a power control or a stability augmentation system, the free play should not exceed ± 3 per cent of total travel.

1.7 WHEEL THROW*

Wheel-type controls are less desirable than stick-type controls for VTOL aircraft, but if they must be used, the wheel throw necessary to meet the lateral control recommendations should be readily obtainable with one hand, and should not exceed 60 degrees in each direction.

This also applies in case of a failure in a power control system.

1.8 CHARACTERISTICS OF TRIM SYSTEMS

The trim system should be of a type that is continuously adjustable throughout its range. In addition, 'press-to-release' and 'press-to-trim' systems may be used.

All trimming devices should maintain indefinitely the setting selected by the pilot, unless actuated by an automatic system. The device should be capable of easy and comfortable operation by the pilot at all times and all points of the flight envelope.

Following any trim system failure, the permanent out-of-trim forces* should not exceed 10 lb longitudinally, 7 lb laterally and 40 lb directionally, at any speed up to V_{Con}.

1.9 CHARACTERISTICS OF THRUST VECTOR CONTROL SYSTEMS

The direction of the thrust vector may be controlled either by a trim-type switch or by a lever, or by any other device acceptable to the pilot.

Any selected setting of the thrust vector control elements should be maintained indefinitely without attention from the pilot. It should be possible for the pilot to select the angular setting for hovering without reference to an indicator.

The acceleration and deceleration usable during a transition should not be limited by the rate at which the thrust vector can be rotated.

In addition, performance and repeatability of the take-off manoeuvre should not be limited by this rate, nor by the accuracy by which a chosen angle setting can be selected without reference to an indicator.

No single failure of the thrust vector control system should cause the thrust vector to rotate to a position, or at a rate, such that the aircraft cannot maintain height or make a safe landing.

After a failure in a power system it should still be possible to actuate the systems necessary for transition.

SECTION 2

LONGITUDINAL STABILITY AND CONTROL

2.1 GENERAL

It is a prime objective of V/STOL that the aircraft be capable of being operated from restricted spaces. It should therefore be possible for a pilot of reasonable skill to make consistently accurate take-offs, approaches and touch-downs in terms of speed and flight path holding. The following sections are intended to ensure that this objective will be met.

In case of emergency operation following a single failure the aircraft should still be capable of operating from restricted areas. The behaviour of aircraft which cannot remain in flight after engine failure should be such that the pilot can in that case either make an immediate emergency landing or can escape.

2.2 BASIC AIRCRAFT INSTABILITY LIMIT

The instability of the basic aircraft should not be so great that, during any longitudinal manoeuvre within the design flight envelope, the input of the stability augmentation system to provide apparent stability, together with the pilot's input, at any time leaves less than 50 per cent of the nominal longitudinal control moment† for recovery.

2.3 STATIC STABILITY WITH RESPECT TO SPEED

With the most critical loading, for all steady forward flight conditions in which the aircraft might be operated continuously including the conditions listed in the following Table, the aircraft should possess positive static longitudinal control position and control force stability with respect to speed. The variation of control position* and control force with speed, at constant power setting, should furthermore be a smooth curve over the complete speed range appropriate to a given configuration. Compliance should be demonstrated over the out-of-trim range stated in the table, with the aircraft trimmed at the reference speed. When it is clear that the aircraft is not required to operate continuously in any one or more of these conditions, a mild degree of instability in that condition may be accepted provided it is not objectionable to the pilot.

Following a failure in the longitudinal stability augmentation system longitudinal instability with respect to speed can be tolerated, provided that the instrument approach and landing is not compromised and that at no time less than 50 per cent of the nominal control moment† in pitch is available in the recovery direction when demonstrating over the speed ranges and from the trim conditions called for in the Table.

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† See Section 5 of the Introduction (TERMINOLOGY).

The following definitions are adopted for the reference speeds in the Table. Configurations are those appropriate to the speeds.

V_{Con}	Conversion speed (see Introduction, Section 2).
V_{MO}	Minimum operating speed. For multi-engined aircraft only. The minimum speed at which performance and control† are adequate to make a safe landing at the desired point with the critical engine failed.
V_{TOSS}	Take-off safety speed. For multi-engined aircraft only. The minimum speed during take-off at which, after failure of the critical engine, performance and control† are adequate either to continue flight and make a normal landing or to make an immediate emergency landing.
V_{PA}	Normal power approach speed for STOL aircraft, or a speed which could be used on an instrument approach in a VTOL aircraft (assuming that a constant approach speed technique is used).
V_{MP}	Speed for minimum power or minimum thrust - approximately the loiter speed or best climb speed. It is of interest only if it is less than V_{Con} .

Steady flight trim conditions for static longitudinal stability demonstration

1. Hovering	
2. V_{Con}	power for level flight
3. V_{MO}	power for 500 ft/min descent
4. V_{PA}	a. power for level flight
	b. power for 500 ft/min descent
5. V_{TOSS}	take-off power
6. V_{MP}	a. normal rated power
	b. power for level flight

Speed ranges for demonstration

(1)	Speed range for hovering is zero to the designated wind speed.
(2)	Speed range for the remaining conditions is ± 20 per cent of the trim speed or ± 20 knots, whichever is greater.

†Limiting control characteristics are given in Section 6.5.

2.4 MANOEUVRE STABILITY

At the most critical loading, at constant speed and power setting, an increase in pull force and a rearward displacement of the stick should produce an increase in normal acceleration and/or an increase in nose-up pitching velocity for all longitudinal manoeuvres within the design flight envelope.

The variation of the force with normal acceleration and/or pitching velocity at all points beyond the breakout force should be approximately linear. In general, a departure from linearity which reduces the local gradient by more than 50 per cent of the initial gradient is considered excessive.

At speeds above V_{PA} the local value of the longitudinal control force* gradient should never be less than 3 lb per g, nor more than 20 lb per g. There should be no undesirable inputs to the longitudinal control system due to changes in normal acceleration produced by gusts, height control inputs, etc. Compliance with the above recommendations should be demonstrated at the appropriate flight conditions defined in the Table of Section 2.3.

After a failure in the longitudinal stability augmentation system, the longitudinal control position versus normal acceleration should be such that, at constant speed, the control displacement from initial trim to offset instability should at no time leave less than 50 per cent of the nominal control moment for recovery throughout the range of allowable load factors or pitching rates. Control forces developed with initial control displacement from trim in the manoeuvres above should always be in a direction to resist displacement from trim. As the instability develops, the force* in an unstable direction should never exceed 10 lb push or 20 lb pull throughout the range of allowable load factors or pitching rates.

Also, after a failure in the stability augmentation system, any static longitudinal instability (speed and manoeuvring sense combined) should be such that, with controls held fixed at the initial trim position for 3 seconds following a disturbance of 5 knots or 0.2 g acceleration or 5 degrees per second, the control required to return the aircraft to trim conditions does not exceed one half of the control moment available from trim to the stops. Trim conditions for demonstrating compliance should be those defined in the Table of Section 2.3.

2.5 TRANSIENT RESPONSE CHARACTERISTICS IN MANOEUVRING FLIGHT

The following is intended as an additional insurance for acceptable manoeuvring characteristics during normal (no-failure) operation. The normal acceleration stipulations apply at all speeds above V_{PA}. The angular velocity stipulations apply at all forward speeds, including hovering.

(a) After a sudden rearwards longitudinal control input sufficient to generate a 0.2 rad/sec pitching rate within 3 seconds, or to develop a normal acceleration of approximately 1.2g within 3 seconds, is made and then held fixed, the time history of normal acceleration should become concave downward within 2 seconds following the start of the manoeuvre, and remain concave downward until the attainment of maximum acceleration.

Preferably, the time-history of normal acceleration should be concave downward throughout the period between the start of the manoeuvre and the attainment of maximum acceleration. Figure 1a shows the normal acceleration response considered acceptable.

(b) During the above manoeuvre, the time history of angular velocity should become concave downward within 2 seconds following the start of the manoeuvre, and remain concave downward until the attainment of maximum angular velocity; with the exception that for this purpose a faired curve may be drawn through any oscillations in angular velocity not in themselves objectionable to the pilot. Preferably, the time history of angular velocity should be distinctly concave downward throughout the period between the start of the manoeuvre and the attainment of maximum angular velocity.

Figure 1b shows the angular velocity response considered acceptable.

Compliance with these recommendations should be demonstrated at the flight conditions specified in the Table of Section 2.3.

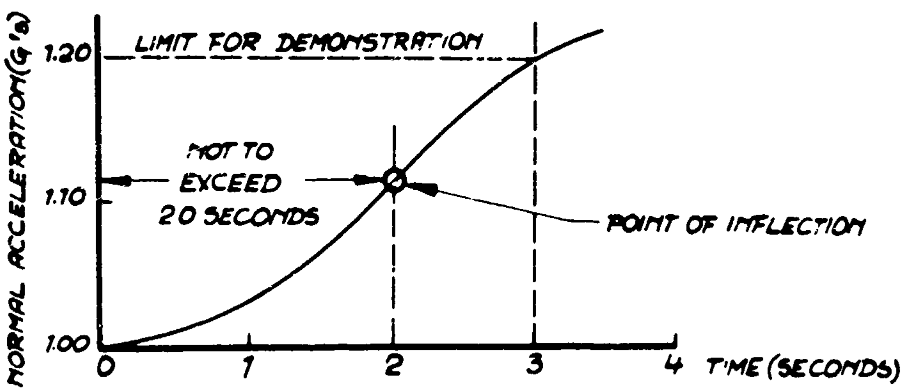

Fig.1a

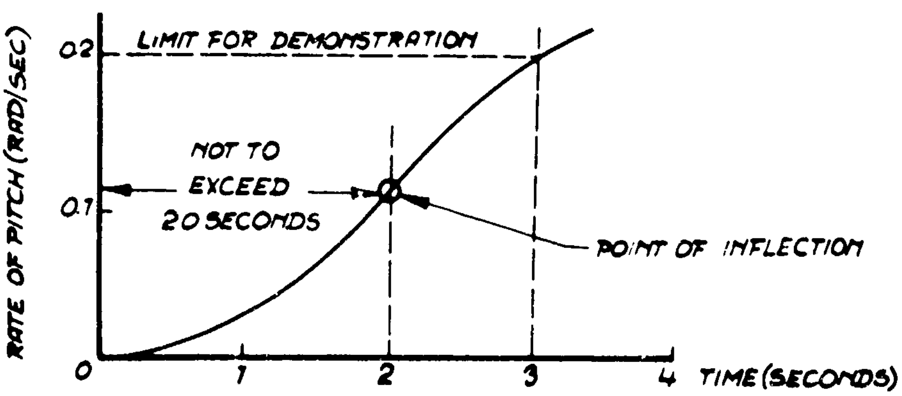

Fig.1b

2.6 TIME DELAY

There should be no objectionable time delay in the development of angular velocity in response to the pilot's control input. The angular acceleration should be in the proper direction within 0.2 second after initiation of longitudinal control application.

These recommendations should also apply after a failure in a power control or stability augmentation system.

2.7 CONTROL FORCE TRANSIENTS FOLLOWING A STEP CONTROL INPUT*

After a step-and-hold input on the longitudinal control from trimmed straight flight, the control force should not fall to zero and should lead the normal acceleration and pitching velocity sufficiently to prevent overshoot.

Following a failure in a power control or augmentation system, the control force with initial displacement from trim should always be in a direction to resist this displacement. Specifically, with an abrupt step-and-hold displacement of the control, the force should resist displacement and should not fall to zero in the first half-second after the control has reached its displaced position.

2.8 APPLICABILITY OF DYNAMIC STABILITY CRITERIA

The following dynamic stability recommendations should apply at all permissible forward speeds and loadings, both in straight and in turning flight.

2.9 DYNAMIC STABILITY

Longitudinal oscillations with controls fixed, following a single disturbance in smooth air, should exhibit damping characteristics not less than given by the normal flight curve in Figure 2. Also there should be no tendency for perceptible small amplitude oscillations to persist.

After a failure in a stability augmentation system minimum damping characteristics should be those of the single failure curve in Figure 2. Small amplitude residual oscillations are permitted, provided they are not objectionable to the pilot.

2.10 COCKPIT CONTROL RESPONSE

When the longitudinal control is abruptly deflected and released, the motion of the control following release should be essentially deadbeat, unless the oscillations are of such frequency and magnitude that they do not result in an objectionable longitudinal oscillation. This should also apply after a failure in a power control system or stability augmentation system.

2.11 PILOT-INDUCED OSCILLATIONS

There should be no tendency for a sustained or uncontrollable oscillation resulting from the effort of the pilot to maintain a steady flight path, or to manoeuvre the aircraft within its flight envelope.

This should also apply following a failure in a power control or stability augmentation system.

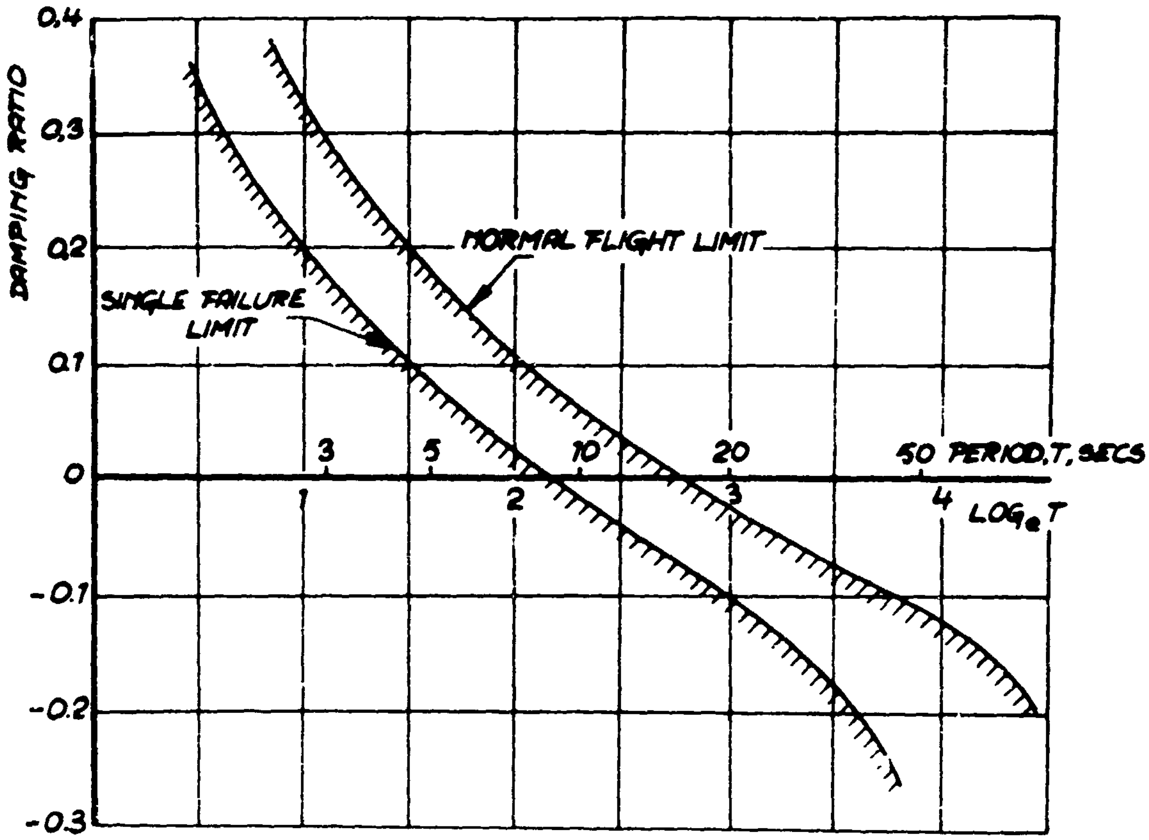

Fig.2

2.12 RESPONSE AND DAMPING[†]

The following is to ensure satisfactory longitudinal control power and sensitivity for manoeuvring while hovering in still air, and to minimize the effects of external disturbances. At any allowable c.g. position and the most critical combination of weight and moment of inertia, the aircraft should possess longitudinal response and pitch angular velocity damping characteristics of at least the values given in the Table on the following page.

In addition, the response for the first inch of control displacement from trim should, for the normal as well as for the single failure case, be equal to or greater than the response per inch of remaining travel

At least the specified values of the response per inch of control deflection and of the damping should be maintained at all speeds up to V_{Con} for VTOL and STOL operation, including the power condition for 1000 ft/min rate of descent at V_{PA}.

[†]The numerical values, and possibly even the form of the scaling factors, will need revision in the light of experience, particularly with large aircraft. See Section 3 of the Introduction.

Longitudinal Response and Damping Characteristics in Hovering Flight

	Response for full control input† *(degrees in first sec)*	*Response for first inch of control displacement** *(degrees in first sec)*	*Damping* *(lb ft/rad/sec)*
Normal Conditions	$300/(W+1000)^{1/3}$	$75/(W+1000)^{1/3}$	$15(I_y)^{0.7}$
After a single failure in a p.c.s. or s.a.s.	$180/(W+1000)^{1/3}$	$45/(W+1000)^{1/3}$	$8(I_y)^{0.7}$

W = aircraft weight in lb. I_y = pitching moment of inertia in slugs ft^2.††

2.13 LONGITUDINAL CONTROL EFFECTIVENESS IN MANOEUVRING FLIGHT

At the most critical loading, when trimmed at any permissible speed and altitude appropriate to a given configuration and engine power, it should be possible to develop at the trim speed, by the use of the longitudinal control alone, the limiting attitude or incidence consistent with the operational flight envelope. The initial conditions for demonstration of this recommendation should be those of the Table in Section 2.3.

This recommendation should also be met following a failure in a stability augmentation or power control system.

2.14 LONGITUDINAL CONTROL EFFECTIVENESS IN TAKE-OFF

Longitudinal control effectiveness should not restrict the take-off performance of the aircraft for STOL operation. Specifically, control effectiveness should be adequate to achieve take-off attitude at no greater than 0.9 times the lift-off speed necessary for demonstrating take-off performance or this lift-off speed less 10 knots, whichever is the lower speed.

This should also apply after a failure in a power control or stability augmentation system.

For VTOL operation, it should be possible to make vertical take-offs in winds up to the designated wind condition. In addition, it should be possible, in conjunction with other controls as necessary, to prevent fore or aft translation during run-up for

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† Some change in this recommendation may be desirable if, for example, other means of controlling fore-and-aft acceleration prove to be effective as a part of the pilot's primary flight control.

†† See Section 4.4 of the Introduction.

take-off, and there should be no objectionable longitudinal (or lateral) attitude changes during starting and run-up to maximum power. For all types of operation, it should be possible to check for proper control functioning during run-up at less than take-off power.

These recommendations should be met with the critical aircraft loading and should be applicable for all surfaces from which the aircraft may be operated.

2.15 LONGITUDINAL CONTROL FORCES IN TAKE-OFF*

With trim optional but constant, the longitudinal control forces required for take-off and during the ensuing acceleration to the take-off safety speed should not exceed 10 lb pull or 5 lb push for normal operation, and 20 lb pull or 10 lb push after a failure in a stability augmentation or power control system has occurred.

2.16 LONGITUDINAL CONTROL EFFECTIVENESS IN LANDING

At the most critical loading, with the aircraft trimmed at V_{PA} or V_{MO} as appropriate, the longitudinal control should be sufficiently effective to land from both shallow and steep approach angles. For VTOL operation it should be possible, in conjunction with the use of other controls as necessary, to make vertical landings from any operationally necessary height in winds up to the maximum designated wind condition.

These recommendations should also apply following a failure in a power control or a stability augmentation system.

2.17 LONGITUDINAL CONTROL FORCES IN LANDING*

For STOL operation it should be possible to meet the landing recommendation of Section 2.16 with forces not exceeding 10 lb pull or 5 lb push. Momentary control forces up to 20 lb pull and 10 lb push are acceptable.

Following a failure in a power control or stability augmentation system, the above control forces should not exceed 20 lb pull or 10 lb push if they are to be held for more than a short time interval, but momentary control forces up to 40 lb pull and 20 lb push would be acceptable.

Limiting forces for VTOL operation are given in Sections 1.3 and 5.5.

2.18 LONGITUDINAL CONTROL FORCES AND CONTROL MARGINS IN SIDESLIPS

With the aircraft trimmed for straight flight in the appropriate flight conditions specified in Section 2.3 for the stability tests, the longitudinal control force* in normal operation should not exceed 10 lb pull or 5 lb push in side-slips up to those specified in Section 3.1. After a failure in a power control system the limiting forces* should be 20 lb pull or 10 lb push.

In addition, in the steady side-slip conditions specified above, a margin of at least 20 per cent of the nominal control moment in pitch should be available, as an allowance for the control of gust disturbances.

2.19 LONGITUDINAL CHANGE-OF-TRIM LIMITS

The change in stick force* needed to trim, following any operationally necessary, or normal, configuration and/or power change, should be as small as possible and, in any case, should not exceed 10 lb pull or 5 lb push when the aircraft is trimmed in the initial condition. After a failure in a power control system, the above forces should not exceed 20 lb pull or 10 lb push.

With the stability augmentation system engaged, out-of-trim conditions resulting from complete disengagement of, or from any failure in, the augmentation system should be such that, with the controls fixed at trim in steady flight in smooth air, the disengagement or failure should not result in a change of pitch attitude of more than 10 degrees, or of rate of pitch of more than 10 degrees per second, or in a change of normal acceleration of more than $\pm$ 1/4 g, within 2 seconds following the disengagement or failure.

2.20 LONGITUDINAL TRIM EFFECTIVENESS

The trimming devices should be capable of reducing the longitudinal control forces to zero for all configurations and flight conditions specified in Section 2.3, and in particular for those in the Table.

Following a failure in the power control system, it should be possible to trim control forces to zero at V_{Con} and V_{PA} (and at V_{MP}, if this is less than V_{Con}) in level flight and at 500 ft/min rate of descent.

SECTION 3

LATERAL-DIRECTIONAL STABILITY AND CONTROL

3.1 SIDESLIP CONDITIONS FOR STATIC LATERAL-DIRECTIONAL STABILITY CRITERIA

Recommendations for static directional stability, dihedral effect, and side force variation apply in straight (zero turn rate) sideslips up to the sideslip angles produced by full directional control with the stability augmentation system in operation, or up to sideslip angles which might be required in normal tactical employment, in the configurations specified for longitudinal stability. Although the recommendations apply over the entire speed range, investigation at the trim speeds designated in Section 2.3, with the exception of hovering flight, will normally suffice for determination of compliance.

3.2 BASIC AIRCRAFT INSTABILITY LIMIT

Basic lateral and directional instability should not be so great that, in the sideslips specified, the input of the stability augmentation system to provide apparent stability, together with the pilot's input, at any time leaves less than 50 per cent of the nominal directional and lateral control moment for recovery.

3.3 STATIC DIRECTIONAL STABILITY (CONTROLS FIXED)*

The aircraft should possess rudder-fixed directional stability such that, in the sideslips specified, right rudder pedal deflection from the laterally level straight flight condition is required to produce left sideslips and vice-versa. For angles of sideslip between ± 15 degrees, the variation of sideslip angle with rudder pedal deflection should be essentially linear in normal operation. Throughout the remainder of the range of required pedal deflection, an increase in pedal deflection should be needed to produce an increase in sideslip.

Following a failure in a stability augmentation system, static directional instability should not be so great that, up to the steady sideslip angles defined in Section 3.1, less than 50 per cent of the nominal control moment is available for recovery. Also, the rate of divergence due to directional instability should be limited. Specifically, when the aircraft is disturbed by a sideslip change of 5 degrees from the trimmed, laterally level straight flight conditions given in Section 2.3, the rate of yaw divergence 2 seconds after return of directional control to initial trim should not be so great that the directional control input needed to return the aircraft to trim uses more than 50 per cent of the control moment available from trim to the stop, nor should the rate of divergence be such as to double the sideslip angle in less than 3 seconds, assuming no correction by the pilot. If, after a single failure in the stability augmentation system, the aircraft possesses negative dihedral effect as defined in Section 3.5, the aircraft should not at the same time exhibit negative directional stability.

3.4 STATIC DIRECTIONAL STABILITY (CONTROLS FREE)*

The aircraft should possess rudder force stability such that, in the sideslips specified, right pedal force is needed to produce left sideslip and vice versa. For angles of sideslip between ± 15 degrees from the laterally level straight flight condition, the variation of sideslip angle with pedal force should be essentially linear in normal operation. At greater angles of sideslip a lightening of pedal force is acceptable, but the pedal force should not reduce to less than one-half the maximum value, nor to less than the allowable friction value.

Following a failure in a stability augmentation system, the directional control forces should not exceed 40 lb during the sideslip manoeuvres specified in Section 3.3. (Section 1.3 covers failure of the power control system.)

3.5 DIHEDRAL EFFECT (CONTROLS FIXED)*

The aircraft should exhibit positive control-fixed dihedral effect in that left lateral control deflection is needed during left sideslip and vice versa. The positive dihedral effect in the sideslips specified should not be so great that more than 50 per cent of the nominal rolling moment is used to trim.

In case of a failure in a stability augmentation system a small amount of negative dihedral effect would be permissible, provided it leaves at least 50 per cent of the nominal lateral control moment for recovery at the sideslip conditions specified in Section 3.1 and provided it does not occur in conjunction with directional instability. Positive dihedral effect should be limited to the same magnitude as for the non-failure case.

3.6 DIHEDRAL EFFECT (CONTROLS FREE)*

The aircraft should exhibit positive control force dihedral effect as indicated by the variation of lateral control force with sideslip. Left lateral control force should be needed during left sideslip and vice versa. The variation of lateral control force with sideslip angle up to the sideslip angles specified in Section 3.1 should be essentially linear in normal operation and the control force should not exceed 10 lb for stick or wheel control. Following a failure in a stability augmentation system, the force needed to offset the permitted negative dihedral effect should not exceed 10 lb. After a failure in a power control system, the lateral control forces should not exceed 20 lb for the sideslips specified in Section 3.1.

3.7 SIDE FORCE CHARACTERISTICS

The side force characteristics should be such that, in the sideslips specified, an increase in right bank angle accompanies an increase in right sideslip and vice versa.

3.8 ADVERSE YAW

At V_{PA} , the angle of sideslip developed during an abrupt rudder-pedal-fixed roll from a trimmed, level, steady 30 degree banked turn to a bank angle of 30 degrees in the opposite direction, without checking, should not exceed 15 degrees. The lateral control deflection applied, and held fixed during the roll, should be at least that required for compliance with the lateral control performance tests. For smaller lateral control deflections the acceptable angle of sideslip will be proportionally smaller.

Also, the sideslip developed in a slow manoeuvre starting from a laterally level condition, generated by a step displacement of the lateral control of such magnitude that a bank angle of 30 degrees is developed in not less than 6 seconds, should not exceed 15 degrees.

For both types of manoeuvre, the rolling velocity should always be in the correct direction; i.e., should not reverse due to the combination of dihedral effect and the sideslip developed. For aircraft which exhibit favourable yaw, the values of sideslip in the favourable direction obtained during these roll manoeuvres should not be so large as to cause objectionable flight characteristics.

In the rolling manoeuvres specified above, the directional control should be adequate to maintain sideslip at the initial trim value.

In the case of a failure in a stability augmentation system, the sideslip developed in the roll manoeuvres specified above should be permitted to reach 20 degrees.

3.9 DYNAMIC STABILITY

Lateral-directional oscillations should exhibit characteristics the same as those recommended for longitudinal oscillations in Section 2.9.

Spiral stability should preferably be positive for all normal flight conditions up to V_{Con} .

In the case of a failure in a stability augmentation system, negative spiral stability should be permitted, provided the rate of divergence at the trim conditions specified in Section 2.3 is not so great that, when controls are released in a steady 10 degree banked turn established from trimmed laterally level flight, the bank angle is doubled in less than 20 seconds.

3.10 TIME DELAY IN LATERAL AND DIRECTIONAL CONTROL

There should be no objectionable time delay in response to lateral or directional control application. In any case the angular acceleration should be in the proper direction within 0.2 second after initiation of pilot control application.

This recommendation should also be met following a failure in a power control or stability augmentation system.

3.11 DIRECTIONAL RESPONSE AND DAMPING†

The following is to ensure satisfactory directional control power and sensitivity for manoeuvring while hovering in still air, and to minimize the effects of external disturbances.

At the most critical combination of weight and moment of inertia, both in and out of ground effect, the aircraft should possess directional response and yaw angular velocity damping characteristics of at least the values given in the Table below. It is considered highly desirable that, for the all-weather operations envisaged, the response should be up to twice these values. In addition, the response for the first inch of control displacement from trim should, for the normal as well as the single-failure case be equal to or greater than the response per inch of remaining travel.

At least the specified values of response per inch of control deflection and of the damping should be maintained at all speeds up to V_{Con} for VTOL and STOL operation, including the power condition for 500 ft/min rate of descent at V_{PA}.

The directional response, at any speed in the conversion range, should not be so high as to cause a tendency for the pilot to overcontrol.

Directional Response and Damping Characteristics in Hovering Flight

	Response for full control input (degrees in first sec)	*Response for first inch of control displacement* (degrees in first sec)*	*Damping (lb ft/rad/sec)*
Normal conditions	$180/(W+1000)^{1/3}$	$60/(W+1000)^{1/3}$	$27(I_z)^{0.7}$
After a single failure in a p.c.s. or s.a.s.	$180/(W+1000)^{1/3}$ (same as normal case)	$60/(W+1000)^{1/3}$ (same as normal case)	$14(I_z)^{0.7}$

W = aircraft weight in lb. I_z = yawing moment of inertia in slugs ft^2.††

† The numerical values, and possibly even the form of the scaling factors, will need revision in the light of experience, particularly with large aircraft. See Section 3 of the Introduction.

††See Section 4.4 of the Introduction.

3.12 LATERAL RESPONSE AND DAMPING†

The following is to ensure satisfactory lateral control power and sensitivity for manoeuvring and to minimize the effects of external disturbances.

At the most critical combination of weight and moment of inertia, at all speeds up to V_{Con} and, in particular, for the flight conditions specified in Section 2.3, the aircraft should possess lateral response†† and roll angular velocity damping characteristics of at least the values given in the Table below. In addition the response for full control input†† should not be less than 10 degrees in the first second, and the response for the first inch of control displacement from trim should, for both the normal and the single-failure cases, be equal to or greater than the response per inch of remaining travel.

Also the lateral response should not be so large as to cause a tendency for the pilot to overcontrol. In particular, sensitivity in hovering flight is considered excessive if, in this condition, the response for one inch of control deflection* from trim is greater than 20 degrees in the first second.

Lateral Response and Damping Characteristics

	Response for full control input†† (degrees in first sec)	*Response for first inch of control displacement* (degrees in first sec)*	*Damping (lb ft/rad/sec)*
Normal conditions	$300/(W+1000)^{1/3}$	$100/(W+1000)^{1/3}$	$25(I_x)^{0.7}$
After a single failure in a p.c.s. or s.a.s.	$300(W+1000)^{1/3}$ (same as normal case)	$100/(W+1000)^{1/3}$ (same as normal case)	$18(I_x)^{0.7}$

W = aircraft weight in lb. I_x = rolling moment of inertia in slugs ft^2.†††

3.13 PEAK LATERAL CONTROL FORCES*

For stick or wheel the peak lateral control force required to obtain the rolling performance specified in Section 3.12 should not exceed 20 lb for the flight conditions given in Section 2.3, except for hovering flight for which the peak force should not exceed 10 lb.

After a failure in a power control system the peak force should not exceed 20 lb at any speed from hovering up to V_{Con}.

† The numerical values, and possibly even the form of the scaling factors, will need revision in the light of experience, particularly with large aircraft. See Section 3 of the Introduction.

†† Some change in this recommendation may be desirable if, for example, other means of providing lateral (sidewise) acceleration prove to be effective as a part of the pilot's primary flight control.

††† See Section 4.4 of the Introduction.

3.14 DIRECTIONAL CONTROL EFFECTIVENESS IN HOVERING[†]

These recommendations apply both in and out of ground effect and to the loading conditions which produce the most critical combination of weight and moment of inertia.

It should be possible to execute a 360 degree turn in each direction while hovering in the designated wind condition. In addition, to ensure an adequate margin of control when starting at zero yaw rate at the most critical azimuth angle relative to the wind, application of full directional control in the critical direction should result in a yaw displacement of at least $60/(W+1000)^{1/3}$ degrees within one second of initiation.

3.15 DIRECTIONAL CONTROL EFFECTIVENESS IN NORMAL FLIGHT

The directional control should be sufficiently effective to maintain laterally-level straight flight in the configurations and speed range specified for longitudinal stability, with a margin of at least 50 per cent of the nominal directional control moment remaining. Following a failure in a stability augmentation or power control system this margin should be at least 30 per cent.

3.16 DIRECTIONAL CONTROL EFFECTIVENESS DURING TAKE-OFF, LANDING AND TAXI

The directional control, in conjunction with other normal means of control, should be adequate to maintain the desired paths during taxi, take-offs, and landings, in the designated wind conditions. Specifically, for STOL operation a margin of at least 20 per cent of the nominal directional control moment should remain during cross-wind take-offs and landings.

It should be possible to make a 360-degree taxying turn in either direction within a circle whose radius equals the major dimension of the aircraft, in winds up to the designated wind conditions.

Except for the taxi cases, the above recommendations should also apply following a failure in a power control system or stability augmentation system.

3.17 LATERAL CONTROL EFFECTIVENESS

Lateral control should be sufficiently effective, in combination with other normal means of control, to balance the aircraft laterally during all flight and ground handling operations and specifically when demonstrating directional control effectiveness.

[†]The numerical values, and possibly even the form of the scaling factors, will need revision in the light of experience, particularly with large aircraft. See Section 3 of the Introduction.

A margin of 50 per cent of the roll control power needed to satisfy the recommendations of Section 3.12 should remain at the most adverse of the above conditions. Under all these conditions the out-of-trim lateral control force* should not exceed 10 lb for stick or wheel, with trim fixed at the initial laterally-level straight flight condition. For all designated asymmetric loadings, the same margin should apply, though not necessarily in combination with other laterally asymmetric conditions.

These recommendations should also apply following a failure in a stability augmentation or power control system, except that the lateral control force* should be less than 20 lb for stick or wheel.

3.18 DIRECTIONAL AND LATERAL CHANGE OF TRIM LIMITS

The changes in directional and lateral control forces* needed to trim any operationally necessary, or normal configuration and/or power change should be as small as possible and, in any case, should not exceed 10 lb for the rudder and 3 lb for the lateral control. After a failure in a power control system these forces should not exceed 40 lb and 10 lb respectively.

In addition, following any such change in configuration and/or power, sufficient control power should remain to satisfy the recommendations of Sections 3.15, 3.16 and 3.17.

In steady flight in smooth air, out-of-trim conditions caused by any failure or disengagement of a stability augmentation system should not, with controls fixed at trim, result in bank or yaw angles of more than 10 degrees or rates of roll and yaw of more than 10 degrees per second within 2 seconds following the failure or disengagement.

3.19 LATERAL AND DIRECTIONAL TRIM EFFECTIVENESS

The trimming devices should be capable of reducing the lateral and directional control forces to zero with zero sideslip in all configurations and flight conditions specified in Section 2.3 and in all asymmetric conditions which are required to be held for more than a short time.

Following a failure in a power control system, it should be possible to trim control forces to zero at V_{Con} and V_{P4} (and at V_{MP}, if this is less than V_{Con}) in level flight and at 500 ft/min rate of descent.

SECTION 4

HOVERING AND VERTICAL FLIGHT CHARACTERISTICS

4.1 CHARACTERISTICS IN GROUND INTERFERENCE REGION

The effects of downwash-ground interference should not result in unsatisfactory characteristics while hovering in any designated wind condition, for all terrain clearances up to the disappearance of ground effect. In addition, there should be no feed-back of unsteady aerodynamic forces on control surfaces to the cockpit controls, nor should there be additional undesirable response from this source.

Following a failure in a power control system or stability augmentation system, downwash-ground interference during the final landing should not result in objectionable flight characteristics.

4.2 HEIGHT CONTROL†

It should be possible to maintain satisfactory control of vertical speed within ± 1 ft/sec by the use of the height control, while hovering in still air at all design hovering altitudes and ground clearances, both in and out of ground effect, with less than ± 1/2 inch movement* of the height control, and without the need for exceptional skill on the part of the pilot.

Following a failure in a power control or stability augmentation system, it should be possible for the pilot to control the vertical speed of the aircraft with sufficient accuracy to make a safe vertical landing. To demonstrate compliance with this recommendation it should be possible to control vertical speed within ± 2 ft/sec, while hovering in still air within the ground effect region, and without the need for exceptional skill on the part of the pilot.

4.3 HOVERING PRECISION†

It should be possible to hover continuously, in the designated wind condition at any height up to the disappearance of ground effect, while any chosen point on the aircraft remains within a circle of 3 ft radius, without acquiring a velocity in excess of 2 ft sec in any horizontal direction, and without requiring undue pilot skill or effort. Following a failure in a power control or stability augmentation system, it should be possible for a pilot of average skill to maintain the same precision during a typical vertical landing.

4.4 VERTICAL THRUST MARGINS

To provide sufficient control of rate of ascent and descent, during vertical take-offs and landings the vertical thrust available out of ground effect should be at

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†Further experience may suggest a better way of expressing this recommendation.

least 1.05 times the aircraft weight for take-off, and 1.15 times the aircraft weight for landing under the most adverse specified altitude-temperature conditions. It should be assumed that 50 per cent of the available control power is being used simultaneously about all three axes. In addition, during take-off, application of full control about any one axis with 50 per cent application about the remaining axes should not reduce the vertical thrust to less than the weight.

The pilot should be able to obtain full control power about all three axes simultaneously, although the thrust margin in this condition is not specified.

4.5 VERTICAL THRUST RESPONSE†

During the final stages of a vertical landing the vertical thrust response should be such that, after a step input of the height control, the lift increase is 60 per cent of the demanded increase in no more than 0.3 second. For demonstration purposes the demanded increase should be 10 per cent of the landing weight at any power setting between hovering and 1000 ft/min rate of descent, in the most adverse conditions for the power unit.

4.6 VERTICAL FLIGHT CHARACTERISTICS

Within the specified limits, the rate of vertical ascent or descent that can be used should not be limited by attitude control power, ability to trim, stalling or buffeting, or by engine malfunction due to intake flow conditions or re-circulation of exhaust gases.

This recommendation should also apply after a failure in a power control system.

†The acceptable aircraft response will depend on height control sensitivity. The optimum sensitivity has not yet been established, but is of the order of 0.15g per inch of control movement.

SECTION 5

TRANSITION CHARACTERISTICS

5.1 ACCELERATION-DECELERATION CHARACTERISTICS

With the aircraft trimmed in hovering flight, it should be possible to accelerate rapidly and safely to V_{Con} at approximately constant altitude. From trimmed steady level unaccelerated flight at V_{Con} it should be possible to decelerate rapidly and safely, at approximately constant altitude to stop and hover. The time taken for these manoeuvres should be that designated by the mission requirements.

It should be possible to execute these manoeuvres without restriction due to longitudinal control power, longitudinal trim, stalling or buffeting, or to engine thrust or response characteristics. There should be no need for the pilot to operate any but the primary flying controls plus power setting and tilt of the thrust vector. These recommendations should apply both in and out of ground effect.

Following a failure in a stability augmentation system or in any power operated system, it should be possible to execute the transition manoeuvre without restriction and to make an approach and landing, under instrument flight conditions. The whole manoeuvre should not be prohibitively long and should, in particular, be compatible with the available landing aids.

5.2 FLEXIBILITY OF OPERATION

In order to demonstrate flexibility of operation, it should be possible to stop and reverse the transition quickly and safely in either direction at any speed up to V_{Con}, and either take a wave-off or make a landing.

This recommendation also applies following a failure in a power control or stability augmentation system.

5.3 TOLERANCE IN CONVERSION PROGRAMME

It should be possible to change from hovering to conventional flight, and vice-versa, within a specified range of fuselage attitudes, safely and easily, without the need for precise programming of engine power, wing or lift engine tilt, etc., in terms of speed or time, such as to require excessive skill and attention from the pilot.

This recommendation also applies following a failure in a power control or stability augmentation system.

5.4 ASCENT AND DESCENT CHARACTERISTICS

For every speed below V_{Con} there should be a configuration in which the aircraft is flyable continuously from military power to 1000 ft/min rate of descent, without

changing this configuration or retrimming by the pilot, and without encountering undesirable effects due to stalling or buffeting including feedback of unsteady forces on the controls.

In addition, control of vertical speed in the above range should not be made difficult by thrust response characteristics. In particular, during the final stages of the approach, the thrust response should be no less rapid than that defined in Section 4.5.

These recommendations should also apply following a failure in a power control or stability augmentation system.

5.5 CONTROL MARGIN

To allow for disturbances and for manoeuvring, the margin of longitudinal control power remaining at any stage in the transition, including the manoeuvres defined by the recommendations of Section 5.4, should not be less than 20 per cent of the nominal pitch control moment.

The same margin should be available following a failure in a power control or stability augmentation system.

5.6 TRIM CHANGE*

The trim change throughout the transition should be small and gradual and, without retrimming, the forces should not exceed 10 lb pull or 5 lb push. Trim changes during the manoeuvres defined by the recommendations of Section 5.4 should be as small as possible and, in any case, not exceed 10 lb pull or 5 lb push.

Following a failure in a power control system these trim changes should not exceed 20 lb pull or 10 lb push.

5.7 RATE OF STICK MOVEMENT*

During transition, with the maximum available rate of change of forward speed, the rate of stick movement to maintain trim† should preferably not exceed 1/2 inch per second and should in any case not exceed 1 inch per second.

This recommendation should still be met following a failure in a power control or stability augmentation system.

5.8 SPEED STABILITY*

To reduce the effect of horizontal gusts, and to allow a reasonably wide band of usable speeds at a given configuration, the change in stick position with change in speed should not exceed 0.1 inch per knot.

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†Some change in this recommendation may be necessary if the stick fulfils some function other than that of maintaining trim (e.g. control of wing tilt).

If 0.1 inch longitudinal control displacement per knot is achieved by stability augmentation or power control system interconnection, then a failure of either system should not result in a change in control displacement with change in speed greater than 0.25 inch per knot.

SECTION 6

MISCELLANEOUS RECOMMENDATIONS

6.1 CHARACTERISTICS OF THE LANDING GEAR

The dynamic characteristics of the landing gear should prevent rebounding on paved or unpaved surfaces and should not in themselves provide a limit to the landing vertical velocities the pilot would otherwise consider acceptable for operational landings, nor should they prevent effective use of the brakes after landing.

Also, when the aircraft is on the ground, unequal action of the individual landing gear members should not require the use of flight controls or brakes to prevent unwanted lateral or fore-and-aft motion.

6.2 CROSS-COUPLED EFFECTS

6.2.1 Gyroscopic Effects

The effects of engine, fan or rotor gyroscopic moments c the dynamic behaviour of the aircraft should not result in objectionable flight or ground handling characteristics. In flight, the elimination of the cross-coupled response during any demonstration maroeuvre should require less than 20 per cent (preferably less than 10 per cent) of the nominal control moment about the cross-coupled axis.

6.2.2 Mechanical Cross-Coupling

Any control displacement should produce no objectionable forces at any of the other controls. For aircraft using power-boosted or power-operated controls, there should be no cross coupling of control forces (unless it is a specific objective of the design).

In case of a failure in a power control system, the force produced at any one control due to full actuation of another should not exceed 5 lb, except for the lateral control, where the force should not exceed 10 per cent of that applied to any other control or 5 lb, whichever is smaller.

6.2.3 Inertial Cross-Coupling

Throughout the speed and height range covered by these recommendations, the application of any roll control input necessary to satisfy roll control recommendations, the other controls being held fixed, should not result in yaw motion, sideslip or pitch attitude change which causes any objectionable or dangerous flight conditions.

This should also apply following a failure in a power control or stability augmentation system.

6.3 SPIN CHARACTERISTICS - TENDENCY TO SPIN

At any possible flight condition appropriate to the type of operation, there should be no tendency for the aircraft to spin following the attainment of stalled conditions on the lifting surfaces, either during normal operation or following any single failure.

6.4 CHARACTERISTICS AT MINIMUM FLIGHT SPEED

6.4.1 Definition of V_{Min}

Minimum flight speed, V_{Min}, is not used as a reference speed, but is defined simply as the lower end of the speed range that can be used at any stage of the transition with a given configuration and power setting. V_{Min} is, therefore, the lowest speed at which all relevant handling recommendations can be met with any given configuration and power setting.

It can often be associated with partial or complete stalling of the wing, as on conventional aircraft. The significance of V_{Min} in this case depends, obviously, on the proportion of the total lift that is generated by aerodynamic means. When this is very small, the effects of stalling may tend to become unimportant.

For aircraft with limited longitudinal control power, V_{Min} can be the minimum speed attainable, in the applicable configuration and power setting at a given c.g. position.

6.4.2 Flight Conditions for Minimum Flight Speed Criteria

The recommendations for flying characteristics at V_{Min} apply to all operations in which aerodynamic lift is significant, at all permissible c.g. positions, for configurations appropriate to take-off, landing approach (including both steep and shallow approaches), landing and wave-off. The characteristics should be checked in smooth air by reducing speed at constant power, by reducing power at constant speed, and by changing configuration at constant power and attitude (if appropriate), in straight, unaccelerated flight. The characteristics should also be checked with normal acceleration up to the limits of the design flight envelope, at constant speed and power. The initial trimmed conditions for all these tests should be those defined in Section 2.3.

6.4.3 Acceptable Flying Characteristics at V_{Min}†

In the case where V_{Min} is established by stalling of lifting surfaces, the flying characteristics at V_{Min} should be characterized by mild nose-down pitching (not more than 10 degrees change in attitude in 3 seconds with fixed controls), moderate settling of the aircraft (less than 0.2g reduction in normal acceleration), and mild or moderate buffet (that which does not cause the pilot concern for the control or structural integrity of the aircraft). Unintended lateral attitude or directional heading changes at the stall are undesirable but, if they cannot be prevented, the changes with controls fixed should not exceed 20 degrees in roll or 10 degrees in yaw within 3 seconds,

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†Further experience may suggest a better way of expressing this recommendation.

following the stall onset. If undamped oscillatory motions occur, about any axis, that are of large enough amplitude to be of concern from the standpoint of aircraft control, they should be no shorter than 5 seconds in period. Prompt recovery from the stalled conditions should be possible by normal use of controls, including power, without excessive altitude 1

Where V_{Min} is determined by characteristics other than stalling, it should be possible to fly the aircraft at all speeds down to V_{Min} in smooth air in steady laterally-level, non-manoeuvring flight for extended periods with average pilot skill and normal use of controls.

6.4.4 Warning of Approach to V_{Min}

The approach to the minimum flying speed should be accompanied by an easily perceptible warning. This warning should occur at a margin relative to the limiting condition such that attainment of the limiting condition can be avoided by normal use of the controls. The margin should be no less than that corresponding to a speed margin at constant power and configuration of between 5 per cent and 10 per cent V_{Min}; nor, in any case, should it be less than 5 knots. Acceptable warning consists of shaking of the cockpit controls, buffeting or shaking of the aircraft, or both. (But see Section 6.4.6 for limitations to stall warning.)

6.4.5 Artificial Warning Devices

A natural warning is much to be preferred, and artificial warning should only be permitted if it can be shown that aerodynamic warning is not feasible.

The device should be of an approved type, and produce an effect similar to aerodynamic warning. Angle-of-attack indication may be useful to the pilot, in addition to the above.

6.4.6 Limits to Stall Warning Effects

Where normal operation of the aircraft, including VTOL operation, involves a period of flight in which stalled, or partially stalled conditions exist at speeds such that there is no significant disturbance or lack of control of the aircraft, any warning in these conditions should not be such as to disturb or distract the pilot. For aircraft whose minimum flight speed is determined other than by stalling or deterioration of handling qualities no warning would be needed, provided that no dangerous flight characteristics occur at the minimum speed.

For aircraft which need artificial warning, operation of the device should not aggravate the deterioration in handling qualities which is used to define the minimum speed.

6.4.7 Avoidance of V_{Min}

It should be possible to avoid the attainment of the minimum flight speed by normal use of the controls at the onset of the warning. In the event of attaining V_{Min} it should be possible to recover by normal use of the controls, with engine power used as necessary, and without excessive loss of altitude or increase in speed. Control

forces* should not exceed 20 lb for lateral control, 40 lb for longitudinal control or 80 lb for directional control.

6.5 POWER PLANT FAILURE

6.5.1 Single-Engined Aircraft

To ensure that the pilot has time to escape following engine failure of a single-engine V/STOL aircraft, the attitude changes in roll and pitch should not exceed 20 degrees in the first 3 seconds following the failure, the controls being free during this period.

6.5.2 Multi-Engined Aircraft

Following failure of the critical engine of a multi-engined aircraft it should be possible to recover at all speeds up to V_{Con}, assuming normal pilot reaction capability. After recovery, margins of control power in the critical direction at least equal to those in the following Table should remain at all speeds up to V_{Con}. These margins should remain available throughout the approach and landing.

Control margins remaining after critical engine failure	
Longitudinal	20 per cent of the nominal control moment available before the failure.
Lateral	50 per cent of the roll control moment needed to satisfy the recommendations of Section 3.12.
Directional	For STOL, 20 per cent of the nominal control moment available before the failure, at all speeds above V_{MO} and V_{TOSS}. For VTOL a response of $60/(W+1000)^{1/3}$ degrees in the first second.

6.6 BOUNDARY LAYER CONTROL SYSTEM FAILURE

6.6.1 Stability

Any longitudinal instability resulting from a failure in a boundary layer control system should be limited to that specified in Section 2.3 for the stability augmentation system failure case.

6.6.2 Stalling Effects

The stall which may be precipitated by a failure in a boundary layer control system should not result in characteristics worse than those defined in Section 6.4.3, controls remaining fixed at the initial trim position.

ADDENDUM

COMMENTS ON THE RECOMMENDATIONS OF REPORT 408

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INTRODUCTION

Concurrently with the 23rd AGARD Flight Mechanics Panel Meeting a Technical Assistance Panel, comprised of specialists on V/STOL aircraft and aircraft handling qualities, met in Athens on July 8 and 9, 1963 to discuss 'Recommendations on V/STOL Handling Qualities' (the original version, dated October 1962, of AGARD Report 408 which is now reproduced in the preceding pages (1-34).

The following attended:

	Company	*Title*
S.J. CRAIG	C.V.C. (Ling Temco-Vought)	Senior Specialist, XC-142 project
R.C. A'HARRAH	North American Aviation	Principal Engineer
J.R. WILLIFORD	Naval Air Test Center	Head, V/STOL Branch
H.C.H. MEREWETHER	Hawker Siddeley Aviation	Experimental Test Pilot
R.K. WILSON	ASD, Wright-Patterson Air Force Base	Chief, HQ Section
THOMAS E. LOLLAR	Boeing	Aerodynamics Engineer
JAMES G. McHUGH	USA Trecom, FT. Eustis	Chief Aeromechanics Group
XAVER HAFER	EWR, Germany (Enwicklungs Ring Süd)	Chief Aerodynamics Dept.
Prof. P. JENISSEN	Ministry of Defence, Germany	Dr. Ing (Research)
I.J PINIER	Centre d'Essais en Vol, Bretigny	Pilote d'Essais
R. MOGNARD	Service Technique Aéronautique	Ingénieur en Chef, Head of VTOL Dept.
CLAUDE J. DURAND	Centre d'Essais en Vol, Bretigny	Ingénieur d'Essais
J.S. ATTINELLO	IDA/WSEG	Special Technical Staff

	Company	Title
J.K. CAMPBELL	US Air Force (NSRQ RAD) (NAVY-FPO-100 N.Y.-N.Y.)	Major
SETH B. ANDERSON	NASA, Ames	Chief, Flight & Simulation Branch
FRED J. DRINKWATER	NASA, Ames	Experimental Test Pilot
WILLIAM KOVEN	BUWEPS, Navy Dept., US	Head, Stability and Control
JOHN P. REEDER (Chairman)	NASA, Langley	Assistant Divisional Chief, Flight Mechanics and Technical Division
J.M H. van VLAENDEREN	NLR Amsterdam	Engineer, Flight Dept.
L R. LUCASSEN	NLR, Amsterdam	Head, Helicopter Dept.

Generally the original Report 408 was regarded by the specialists as an excellent attempt to provide comprehensive handling criteria for the class of aircraft considered. Nevertheless several criticisms could be offered, in many cases accompanied by suggestions for improvement. The criticisms fall into two categories, the first of a general nature being concerned with the scope of the Report, the other being directly concerned with specific recommendations. In addition to the verbal comment given during the discussions, several of the specialists have also offered written comments.

The present draft is an attempt to present all the comments made in an organized manner. Extensive written comments and written comments that summarize comments given during the discussions have been quoted in verbatim where this seemed appropriate. Added to the draft, as Appendices I to IV, are the Report of the Chairman to the Flight Mechanics Panel as well as a summary by the Chairman of the Review Panel and rough notes of the Chairman and the Secretary of the V STOL Handling Qualities Working Group.

Appendix V contains remarks on the comments made by the Technical Assistance Panel which follow.

COMMENTS MADE BY THE TECHNICAL ASSISTANCE PANEL

Presentation of the Report

1. Report 408 requires improvement in the organization. Specific suggestions made at the Meeting are

   (i) 2.9 should be 2.8 1, etc.
   (ii) The Cooper rating scale should be a separate Appendix.

2. The report requires re-editing to improve the wording for clarity.

3. Background and reference material should be published as an amendment to the report.

Introduction to the Report

Applicability

4. The report primarily considers VTOL aircraft; STOL aircraft and helicopters are inadequately covered.

5. On the other hand several of the criteria, in particular those on response and damping, are too strongly based on helicopter experience and the applicability to VTOL aircraft is questionable.

6. A more precise definition of V_{con} is desirable. A suggested definition is $V_{con} = 1.05\ V_{stall}$ (clean, idle power, airplane configuration).

7. A separate section, more extensively covering ground handling, should be added.

4.1 The Level of the Recommendations

8. The visibility conditions to which the recommendations apply have not been adequately defined by 'All-weather instrument flight'.

9. Ames: "In reference to all-weather instrument flight conditions it appears appropriate to point out more specifically the degree of all-weather operation desired; i.e. the minimum ceiling and visibility for which the requirement is to be applied. For example, following a stability augmentation failure, a vehicle may be satisfactory to land with conditions of 300 feet and 1/2 mile, but unsatisfactory for 100 and 1/8 conditions."

10. Hawker: "A further, general, point which we would query is the statement that the 'proposals for normal operation refer to all-weather, instrument flight condition'. This emphasis on instrument flight seems unrealistic in the light of current experience of instrument flight with V/STOL aircraft. To the best of our knowledge, the only available V/STOL experience under such conditions is restricted to helicopters, and no experience is available on other forms of V/STOL aircraft whose handling characteristics can differ markedly from those of helicopters. From our own experience a V/STOL capability permits operation - without recourse to instruments - in lower weather minima than conventional aircraft. However, completely blind operation may well need facilities almost as complex as those needed for conventional aircraft under the same conditions. Unless it is intended that all V/STOL aircraft should be operable under completely blind conditions (which would seem unwarranted in the present state of the art), a clear distinction should be drawn between the requirements for visual flight and those for instrument flight. In any event the majority of available V/STOL data being based on flights under visual conditions, it is extremely difficult to define reliably the requirements for instrument flight."

11. "Occupant(s)" rather than "pilot" must be able to escape.

12. The option to escape should also be available in the case of multi-engined aircraft. (see also point 86).

3.2 Wind Conditions

13. It is recommended also to specify gust conditions on the basis of presently available data; B-66 tests are mentioned as a possible source by James G. McHugh.

3.3 Simultaneous Use of Controls

14. There is insufficient proof either for or against this. It may be better to leave out this section for the time being.

15. T.E. Lollar: "Both simulator and flight test work have shown rare usage of simultaneous complete control inputs in non-emergency flight. Conventional aircraft with elevons or rolling tails do not provide for simultaneous full pitch plus roll control either. This requirement should be re-evaluated to determine if it is justifiable, in view of severe design penalties involved. The requirement might be met by overbleed of engines for short periods of time.

16. AFFTC, Edwards AFB: "Some existing helicopters and proposed VTOL aircraft restrict longitudinal/lateral control combinations to a 'diamond' shaped limit in which full control cannot be obtained simultaneously about both axes. It is very desirable to have a 'square' shaped limit to eliminate this restriction.

17. Full control power should be obtainable on a hot day.

Terminology

18. NATC: "Control power" should be defined as the movement about the aircraft c.g. that is produced by a unit control movement.

19. Sensitivity should be changed to "control sensitivity".

Flight Instrumentation and Control Systems

20. Perhaps stability augmentation systems should be covered here too. Apparently only rate damping systems have been considered. Damping washout and attitude stabilization systems are two possibilities that have been mentioned at the meeting.

Classification of Aircraft

21. Different configurations, as well as different operational usage, will demand different requirements. It has been suggested to differentiate between VTOL and STOL as well as to divide aircraft into operational classes. (See also points 42, 45 and 47).

Section 1

1.2 Breakout Forces

22. Recommended to raise the upper limit for stick type height controls to 4 lb.

1.3 Control Force Gradients

23. There should be no discontinuities in the force gradients.

1.4 Height Control Systems

24. No limits on height control movements or force gradients are given.

1.5 Trim Systems

25. "Press to release" and "Press to trim" systems are desirable.

26. The "device" should be defined.

Section 2

2.3 Static Stability with Respect to Speed

27. Ames: "Although a requirement for stability with respect to speed is necessary, a further consideration for angle-of-attack stability is needed. This stems from experience in operating STOL aircraft such as the BLC C-130 and the Breguet 941. In these aircraft it was necessary to use angle-of-attack information for reference during approach. The pilot is therefore more angle-of-attack stability conscious than speed-stability minded. In accepting a mild degree of static instability, for conditions where the aircraft is not expected to operate continuously, the statement should read ... 'provided as acceptable margin of warning is available to the pilot'. This appears to be more meaningful than saying something is 'acceptable' as long as it is not 'objectionable'".

28. Bottom of table: Speed range for hovering should be ± designated wind speed.

2.4 Manoeuvre Stability

29. For STOL operation manoeuvre instability cannot be tolerated in the emergency case.

30. It would be desirable to specify a relationship between stick force and angular response.

2.5 Transient Response

31. Case of initial negative g is not covered. This type of response is characteristic of delta aircraft.

2.6 Time Delay

32. According to simulator studies presented in Grumman Research Department Report RE-162, 0.2 sec is inadequate.

33. Does not apply to other means of fore-and-aft acceleration as presently stated.

2.9 Dynamic Stability (Also covers 3.9)

34. For conventional ILS approaches, longitudinal short-period oscillations in the 5-15 sec range are a problem area. In this range an increase in damping is required. Possibly this effect is more prominent in conventional flight because of stronger g-response. Nevertheless the present recommendation seems an oversimplification.

35. Spiral stability should be adequate for ILS approaches if time to double amplitude is 8 sec.

2.12 Response and Damping (Also covers 3.11 and 3.12)

36. The values for control sensitivity and damping (derived from Tapscott's work) appear to be reliable. Total control power has been extrapolated from available control movement and the given values are questionable. This is unfortunate as total control power is a more important design criterion. For visual flight, total control power required has been established by NASA research. The numbers are available in NASA reports. A Princeton report offers lower control power limits obtained fron simulator tests.

37. Washout of artificial damping for large control deflections can be a means to make better use of available control power. Perhaps this could be included in the recommendations.

38. Present longitudinal control power requirement is for still-air hovering. There appears to be a need for requirements in limiting wind (35 knots). The same applies to lateral control power in limiting cross wind.

39. Hawker: The comments that follow are based entirely on flight experience in visual conditions.

    Firstly, the maximum hovering control power (or moment) is not only a function of the aircraft's weight, but also of its susceptibility to aerodynamic and other forces in hover and transition. For example, a helicopter is affected far more by side-winds than a jet-borne V/STOL aircraft and for that reason will need relatively greater yaw power. In pitch, the major requirement on control power may be the aerodynamic out-of-trim in the middle of transition. Roll control requirements may also be dictated by aerodynamic effects in transition or by ground effects. In our own experience, such factors can demand higher maximum control powers than those dictated by hovering control, pure and simple.

40. Secondly, one of the most important parameters in the hover is control sensitivity. The P.1127 owes much of its success to the provision of adequate sensitivity and, in one axis at least, several times the Report 408 value has been found to be necessary.

41. Hawker: Thirdly, while damping might be necessary for some aircraft, it is certainly not necessary for all. The majority of all P.1127 flights have been made with no artificial damping and the handling has been found to be satisfactory by all the pilots, British and American, who have flown it.

42. Ames: Although the answer to the effect of size and weight on response is far from complete, it would seem desirable to update the existing requirement with flight data where available. As discussed in Reference 1, flight data does not agree with the present specifications, and it would be more accurate to specify response as a function of aircraft type. In this way the X-14A results would be used to represent fighter type aircraft requirements and the BLC C-130 and 941 aircraft results used for STOL requirements for cargo-transport types. Values for longitudinal response should be 0.6 rad/sec^2 and 0.3 rad/sec^2, for normal and emergency conditions respectively, for hovering of fighter aircraft regardless of size. Response for STOL operation of cargo-transport type aircraft should be 0.6 rad/sec^2 for normal operation.

43. Ames: With regard to damping requirements, flight experience has shown greater leniency for the SAS failure case, in fact, negative damping can be tolerated for the longitudinal axis. This suggests that no redundancy would be required for the SAS system.

44. Ames: The effect of first-order control system time lags is not included in the present recommendations. As discussed in Grumman Report RE-162, the effect of an increase in the time constant is to increase the damping required for satisfactory handling qualities, the increase being largest when control sensitivity is high. A suggested criterion might be that a 50% increase in damping is required if the time constant is increased above a value of 0.2 sec.

45. Ames: As discussed previously for the longitudinal response case, the requirements for yaw response should be given in terms of class of aircraft, regardless of size, the yaw response should be 0.5 rad/sec^2 and 0.25 rad/sec^2 for normal and emergency operation respectively. For STOL operation of cargo-transport types the required response should be 0.25 rad/sec^2 for normal operation. The recommendation for doubling the directional response for all-weather operation appears to be slanted to cover helicopters of which some types are sensitive in yaw, and not V/STOL aircraft in general. In addition, as mentioned earlier, any change in the magnitude of response should be tied in with a weather condition. Because of the lack of specific information, and considering the associated performance penalty, it is suggested that special reference to magnitude of control response for all-weather operation should not be included, as is the case for the longitudinal and lateral axes.

46. Ames: In reference to high directional sensitivity the words...."in the conversion range" should be deleted since high sensitivity is not desired at <u>any</u> speed or condition. The damping requirements should be stated to reflect the need for only the basic aerodynamic damping following a SAS failure.

47. Ames: For hover, the lateral response should be 1.8 rad/sec^2 and 0.75 rad/sec^2 for normal and emergency operation, respectively, for fighter-type aircraft. For STOL operation of cargo-transport types, the response should be 0.4 rad/sec^2 for normal operation. Preliminary test results with the variable stability and control X-14A show no appreciable reduction in desired lateral response with an increase in speed from hover to 40 knots. Experience has shown a significant effect of lateral-directional coupling on pilot opinion of the overall turn entry characteristics. As a result, the requirements should allow use of rudder for turn coordination in STOL operation.

48. T.E. Lollar: In the writer's paper presentation* to the Flight Mechanics Panel, it is shown that the aeroplane pitch damping should not be less than 0.75 sec to ensure good closed-loop system stability. Under IFR conditions the pilot is nearing his limit as a stabilizing element for damping less than this value. This is in good agreement with the variable stability S-51 helicopter work, done at NASA-Langley, for pitch damping. This damping level is a function of the input disturbance bandwidth, but is a realistic lower limit to provide a system crossover frequency of between 1 and 2 rad/sec. It is therefore recommended that the AGARD pitch damping recommendation apply, except that the pitch damping should be never less than 0.75 sec for IFR conditions. Also, this damping level must increase if any appreciable lags are present in the control system.

49. T.E. Lollar: Desirable values for airplane pitch sensitivity are also defined in the writer's paper. This paper may be used as a design tool for various classes of VTOL vehicles, if information about the nature of the disturbance input (gusts) is known. The airplane pitch sensitivity boundaries delineated in the paper are also in good agreement with the Langley helicopter work, and are mathematically definable, so as to be useful for extension to different types of vehicles.

2.14 Longitudinal Control Effectiveness in Take-Off

50. The limit of 0.9 times the lift-off speed is acceptable but the 10 knot absolute limit is considered too high. The Breguet is rotated at 0.9 V_{TO}, which is V_{TO} minus 6 knots. An absolute limit of 5 or 6 knots would seem more realistic.

2.16 Longitudinal Control Effectiveness in Landing

51. The possibility of use of power for the flare should be included.

Section 3

52. Wind conditions for STOL operation should be specified.

3.5 Dihedral Effect (Controls Fixed)

53. Ames: In the recommendation for maximum allowable positive dihedral effect, the requirements should be worded to include flight in a given magnitude of cross wind. This more explicit use of cross wind follows as a result of the P.1127 experience in the Farnborough Air Show.

3.8 Adverse Yaw

54. STOL studies have indicated that rate of sideslip is also important. A limit of 2^{o}/sec has been suggested.

55 For the SAS failure case the sideslip reached in the specified manoeuvres should not be so great that fin stall is reached. The present 20^{o} limit would, for example, be unacceptable for the C-130.

* A Rationale for the determination of certain VTOL Handling Qualities Criteria.

3.10 Time Delay in Lateral Control

56. 3.10 does not apply, presently, to other means to control lateral acceleration as part of the primary control.

3.14 Directional Control Effectiveness in Hovering Flight

57. The 360° criterion appears to be based on helicopters. For fighter-type aircraft a 180° turn would suffice.

3.17 Lateral Control Effectiveness

58. Ames: The value of the margin in lateral control appears to be excessive and confusing in its application. It is suggested that a margin of 10% in lateral control moment be available to balance the aircraft laterally to cover configurations like the C-130 which are performance limited because of lateral control effectiveness.

3.18 Change of Trim Limits

59. The helicopter case: from take-off power to autorotation a directional trim change of 30 lb should be allowed.

Section 4

4.1 Characteristics in Ground Interference

60. Ames The present requirement does not permit <u>any</u> feedback of unsteady aerodynamic forces on cockpit controls. It would appear that this could eliminate all but power boost controls. It is recommended that the word "objectionable" be added. In addition, for the failure case the down-wash interference could be allowed to be "objectionable" but not "unsafe".

4.2 Height Control

61. In addition to control movement, a value of g/inch should be specified.

62. It should not be required to hover continuously in ground effect.

4.3 Hovering Precision

63. Precision of height control should be included.

64. How long is "continuously" for demonstration? Is one minute sufficient?

65. Ames For hovering precision it is suggested that a vertical velocity limit or altitude restraint be included as well as the horizontal limits. For the failure situation some relaxed margin should be permitted.

66. Hawker: We are puzzled by the requirement of Section 4.3 (Hovering Precision). Is this really intended to apply to all V/STOL aircraft, or is it not more realistic for "flying crane" devices?

4.5 Vertical Thrust Margins

67. 50% static control input is generally considered too high. It has been suggested to use instead control required for the worst trim conditions (- g. + wind) in addition to either:

(i) Short time control inputs for stabilization in the face of disturbances.
(ii) Control inputs to perform a specified manoeuvre.

68. Hawker: On the question of height control and vertical thrust margins, we feel that the proposals are somewhat pessimistic and should also be defined rather differently. The important parameter at take-off is surely the T/W ratio <u>in</u> ground effect (assuming this to be worse than the free-air T/W). Our experience has shown that a T/W marginally in excess of 1.0 is sufficient for take-off and transition to forward flight. For general hovering and landing a free-air ratio of 1.15 is generous. A minimum of 1.05 can be tolerated and "with a T/W ratio of about 1.10 the aircraft feels quite lively and can be thrown around to a surprising degree" (Hawker pilot's comments).

69. Hawker: Finally, we feel that the requirement to consider simultaneous use of large proportions of the control in all three axes is quite unrealistic. Our experience indicates that this condition can only arise on aircraft with completely unacceptable handling qualities or if the pilot is quite incompetent. We have also found that pilots soon learn to minimise their control movements when the T/W margin is small.

70. Ames: With regard to vertical thrust margins some mention should be made of the allowable use of lift platforms.

Recent experience with the 100 ft travel height-control apparatus has indicated that values of thrust margin as low as 1.025 g and 1.1 g are satisfactory for take-off and landing respectively. The effect of first-order time constant is adequately taken care of in the present requirement of 0.3 seconds.

The requirement for <u>full</u> control power about all axes simultaneously is not evidenced in practice. A value of 50% is more realistic. For this condition the vertical thrust margin should not deteriorate to less than 1.025 g.

4.6 Vertical Flight Characteristics

71. Wind conditions should be specified in connection with intake flow.

Section 5

5.1 Acceleration and Deceleration Characteristics

72. The controls are named too specifically. This should not be necessary as ease of control is taken care of by Section 5.3.

73. For the emergency case weather minima of 200 ft and 1/4 mile are recommended.

5.3 Flexibility of Operation

74. ...stop, operate steadily for a short time, and reverse....

5.4 Ascent and Descent Characteristics

75. Does not cover the lift engine case.

76. Military power in some configurations above structural limits.

5.5 Control Margin

77. Ames: The margin in longitudinal control power for disturbances and manoeuvering for STOL operation should be 1.2 g instead of the 20% of the nominal pitch control moment currently in use. The 1.2 value follows from STOL experience with the C-130 and 941 aircraft.

5.6 Trim Change

78. Trim change caused by stopping or starting of lift engines should be specifically included.

5.7 Rate of Stick Movement

79. Magnitude of acceleration and deceleration should be specified

Section 6

6.1 Characteristics of the Landing Gear

80. Unwanted yawing motions should be included.

81. Ames: Delete ..."in paved or unpaved" and include ..."any surface"...In addition, "objectionable rebounding" should be used since some degree of rebounding is inevitable at maximum vertical velocities. Some recommendation should be made to limit the magnitude of the lateral divergence during ground roll-out, as exemplified in the behavior associated with the narrow gear of the C-130 aircraft.

6.2.1 Gyroscopic Effects

82. Ames: The recommendation on allowable gyroscopic coupling should be more severe, the existing specification reworded to state ..."The effects of engine, fan or rotor gyroscopic moments should not produce any discernable dynamic behavior of the aircraft"...In addition, for the failure of the SAS equipment, not only should the present margin be specified but also the manoeuver requirements should be included. For example, in a yaw pitch coupling case...."the degree of pitch induced by a full rudder input held for 3 seconds"... could be specified. The tolerance should be phrased to express no "unsafe" operation.

83. James G. McHugh: Conclusion 5 of Grumman Report RE-162 states "VTOL flying qualities requirement would not be overly cautious in allowing no gyroscopic coupling at hover".

6.3 Tendency to Spin

84. Spin characteristics would have to be demonstrated. It has been suggested to delete this paragraph.

6.5 Power Plant Failure

85. It has been proposed also to define transient effects after engine loss, for example by specifying attitude limits or a maximum altitude loss. Such a recommendation should include a one-second delay on the part of the pilot.

86. A proposal offered for differentiation into safety classes is given in the following table*.

	A *Bail Out*	*B* *Emergency Landing*	*C* *Mission Accomplished*
Longitudinal	$< 20^o$ in 3 sec	10% margin	20% margin
Lateral	$< 20^o$ in 3 sec	25% margin	50% margin
Directional	$< 20^o$ in 3 sec	25% margin	20% margin
Vertical	depends on ejector seat characteristics	< 10 ft/sec at touchdown	> 0

6.6 Boundary Layer Control System Failure

87. Ames. For a BLC system failure it should be stated that...."no unsafe directional or lateral asymmetry result"...The present allowable divergence is too lenient for a landing approach situation. In addition, the BLC system should be designed such that loss of one power component does not result in an altitude loss greater than 50 ft when trimmed at the design approach speed.

A recommendation concerning operation in reversed thrust should be included.

88. Trim changes due to BLC loss on control surfaces only should be covered also.

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* Note by the Secretary: At present 6.5.2 applies to control characteristics only and not to mission capability. Options for operational safety have been identified in the table to 2.3. Further comment is given in Section 4.1 of the Introduction. Judging from various comment this spread-out presentation is confusing. The proposal herein should constitute an improvement in this respect.

APPENDIX I

Report of the Chairman of the Review Panel of AGARD Report 408 to the Flight Mechanics Panel - July 1963

The Review Panel could not revise the report but I believe the exchange of experience, ideas, and viewpoints was very beneficial. Twenty people attended.

Summary and Conclusions of the Chairman are as follows.

1. A strong feeling was expressed that Report 408 provides a good design guide in its present form.

2. However, the Report is considered inadequate at this time in scope and in validity, due to lack of experience, for it to be used directly as a design specification.

3. Major points in which it was found lacking are in the validity of control response figures, particularly for roll and yaw in hover, and the effect of size on the required response. Ames feels that response as a function of class of airplanes (i.e., fighter, transport, etc.) makes more sense than as a function of weight or size, and they think they have data to confirm this

4. Also, there seemed to be a feeling that STOL airplanes were not considered adequately. For instance, control response is required to be constant throughout the range from hover to V_{con} ; whereas the real need for roll response may be less, and for pitch more, for the STOL case than for VTOL. In addition, helicopter requirements are not dealt with completely.

5. Report 408 also requires some corrections, some additions, and changes in its organization and paragraph numbering for clarity. It should also be edited for grammar, sentence structure, etc., for clarity.

6. It is not considered worthwhile to attempt revision of the Recommendation at this time, unless it is intended that it become a requirement If it is desired to make it a requirement, enough new information seems to be becoming available for a reasonable requirement to be developed in one to two years. A revision or conversion to a requirement would require considerably more work than for Report 408. In fact, full time for somebody on such a revision would be necessary.

7. If conversion to a requirement is the goal, a Working Group should be set up, all members being knowledgeable in the field, with direct military representation if the specification is for military aircraft. The group should be small, preferably not over four persons, in order to get the job done

8. As for research, the needs seem to be

   (a) Determine control response, stability and damping requirements, particularly under precision instrument approach conditions for fighter, transport, V/STOL, and for similar STOL classes

(b) Get operational experience in the field with V/STOL and STOL aircraft.

Both of these require that more aircraft of the V/STOL and STOL types be made available for thorough flight research with the objectives (a) and (b) in mind. Variable stability and control aircraft are being used to study handling problems, but they cannot solve all the problems.

APPENDIX II

Summary of Noteworthy Comments on AGARD Report 408 from the Athens Meeting of the Review Panel, July 1963, by John P. Reeder, Chairman of Review Panel

The following comments from the two-day review session are considered of importance.

1. The report treats VTOL aircraft primarily, and STOL aircraft are inadequately considered as a class.

2. Helicopters are inadequately treated in several respects, such as control requirements for torque compensation and requirements for autorotation. Also, other comments were made to the effect that control response requirements are based too strongly on helicopter experience. There does seem to be a legitimate question at present at present as to whether or not satisfactory response in the helicopter case is adequate for other types of VTOL aircraft.

3. The requirements in the Report for roll response in hovering were found to be too low in the case of the P-1127, and in pitch too high in the case of the Balzac. Of course, there has been a large difference in the damping of the two aircraft as flown. Also, the control response specified for transition flight is generally thought to be too high.

4. Ames personnel expressed the viewpoint that control response and damping in hovering should be specified by class of aircraft and not by weight*. They will continue to acquire data and analyze it for confirmation of this concept.

5. It was generally agreed that the report is written as a designer's guide rather than as a flight demonstration manual. The line is hard to draw, however, and the report follows the pattern of other such documents.

6. It was suggested that the control response specified be required for hot-day conditions.

7. Maintaining specified control power with simultaneous application of all controls, and maintaining the specified T/W ratios with control use as specified, is too severe and unrealistic a requirement in practice. It was stated that such a requirement would dictate the kind of lift and propulsion system used. Augmentation systems can greatly reduce the severity of a requirement for the simultaneous application of control.

8. It was suggested that instead of visual or instrument flight rules (VFR or IFR) the level of requirements be based on weather minima to be used in operation.

9. It was suggested by the German representative that attitude control and stabilization systems need specification in V/STOL Recommendations.

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* See the note by the Chairman following (20) on page 52.

10. It was suggested by the French that there should be three levels of safety to be considered for VTOL aircraft in case of engine failure, depending on the aircraft and mission. These are:

(a) Single-engine military.
(b) Multi-engine military where a hard landing under control can be accepted.
(c) Civil transport where landing is not acceptable and adequate control must be maintained.

The following type of requirement is suggested:

Level of Safety

Axis	*Ejection*	*Emergency Landing*	*Continue Flight*
Longitudinal	$< 20^\circ$ attitude in 3 sec	10% control margin remain	20% control margin remain
Lateral	$< 20^\circ$ attitude in 3 sec	25% control margin remain	50% control margin remain
Directional	$< 20^\circ$ heading in 3 sec	25% control margin remain	20% control margin remain
Vertical Speed	-	< 10 ft/sec	> 0

11. It was suggested by US BUWEPS that the background and reference material for the Recommendations be published as an amendment to the Report. This would give the user the capability of using judgment in application.

12. Also, the BUWEPS stated that its experience indicates that lateral-directional oscillations need stiffer damping requirements for 5-10 second periods than the Recommendations suggest.

13. It seems that the organization or format of the Report is poor in places. For instance, paragraph 2.9 should be 2.8.1, a subdivision of 2.8, as is done in the US Mil. Spec. H-8501A. Also, there are several other places noted by the Chairman where incorrect words and wording were used in the final editing, where misinterpretation is possible, or where ideas are vaguely expressed.

14. Objections were raised to the terminology "all weather". It was suggested that this terminology be replaced by the more definitive words "instrument flight", and that instrument flight and its implications to these Recommendations be defined in the Introduction.

15. The US NATC thought there was not enough on ground handling characteristics and suggested that a section be devoted to such requirements.

16. It was suggested that a more specific definition of V_{con} is needed. The USAF suggested that V_{con} be considered 1.05 V_{stall} clean, idle power, in the airplane configuration.

17. It was noted that speed stability has a large influence on hovering control and damping requirements in the presence of gusts. It is true that the stated requirements are based on experience with only normal gustiness and normal values of speed stability.

18. The British suggested that the rolling moment due to dihedral effect in slips and sidewind should be more stringently limited with respect to lateral control required to trim. They and the Ames delegation thought the recommendations should specify a wind condition for satisfying the requirements. It was suggested that a VTOL aircraft should meet all the hovering requirements in a 35-knot wind.

19. The concept of stick force per g for longitudinal manoeuvering feel may not produce satisfactory feel at low speed. A force proportional to pitching velocity is a logical source for low speed feel, although suitable numbers are not yet available from experience.

20. It was suggested by Ames that no damping need be specified for the single failure case since experience has shown that VTOL aircraft are flyable without damping augmentation in visual flight. With failure about a single axis, therefore, reversion to basic airframe ought to be suitable for emergency.

• Note by the Chairman relating to (4) on page 50:

The extrapolation for size in the control response requirements is expressed in terms of weight. However, the extrapolation is based on the idea that, as aircraft grow in size, the pilot will move away from the center of gravity, regardless of the exact configuration. Therefore, he will be subjected to linear accelerations due to angular accelerations about the three axes which are proportional to the size or a linear dimension of the aircraft. It is though that the pilot relates the control response desired, and also the degree of satisfaction with the response of the aircraft to gusts and other disturbances, to the linear accelerations acting on him. Furthermore, the pilot of an aircraft of large sizes is well aware of the displacements of the extremities of the aircraft when near the ground or other obstacles.

For any given angular motion of the aircraft these displacements increase in proportion to the linear dimensions, so the pilot will limit his manoeuvers accordingly. Since weight, W, is proportional to a linear dimension cubed, l^3, the linear acceleration to which the pilot relates his control response requirements and the displacements of the aircraft extremities in manoeuvers is proportional to $W^{1/3}$, where W becomes a normalizing factor. The term $(W + 1000)$ comes from a curve-fitting process which was performed with the range of weight of helicopters available at the time the relationship was derived. The work at Langley tends to confirm the form of the extrapolation with helicopters up to 30,000 pounds gross weight. From another viewpoint it would seem unreasonable to require constant angular acceleration with increasing size because inertia increases at a greater rate than available control moments tend to.

21. It was pointed out that in considering single failure cases the height control system was not included. In reducing the time constant of the thrust response for height control lead networks may be required, depending on the system used. Failure of such lead networks may result in unsatisfactory or dangerous hovering height control characteristics.

22. The longitudinal control requirements for STOL take-off cannot be met in entirety by the Breguet 941, a STOL aircraft specifically, although it is judged to have satisfactory characteristics. The control is adequate to attain take-off attitude at 0.9 take-off speed, but not at 10 knots less than take-off speed (see 2.14). It is suggested that the Recommendations specify only 0.9 take-off speed. It must be remembered, however, that the longitudinal acceleration of the 941 as a STOL aircraft will not be as great as one designed for VTOL capability. Therefore, a larger margin than 0.9 take-off speed may be required for the VTOL overload case to allow adequate adjustment without exceeding minimum take-off, or take-off safety speed.

APPENDIX III

Rough Notes on the Review of AGARD Report 408 by John P. Reeder

Not specific enough definition of V_{con}.
Control response on hot day.
Craig, C-V

Not enough on ground handling.

Make section heading on ground handling.

Too broad and general. Too much helicopter in it.
Object to "all-weather" (call "instrument flight"
and define.
Williford

Define operating limits in terms of weather mimima.
Anderson

Define terms like "all-weather" in Introduction.
J.K. Campbell

Implication of requiring these for IFR.
Need clarification of VFR or IFR throughout.
Drinkwater

Format:

$$\left.\begin{matrix}2.8\\2.9\end{matrix}\right\}\text{ examples }\left\{\begin{matrix}\text{2.8 should be a heading}\\\text{2.9 should be under 2.8, etc.}\end{matrix}\right.$$

Wilson

V_{con} better defined.
Specify a wind condition.
McHugh

General section on safety outlining provisions for safe
landing for any single failure case.
Germans

Three cases of safety in case of failure. Should consider
control requirements separately for three types. Also,
it is a VTOL requirement, not STOL.
Durand and Koven

Stronger preface on applicability - military wants
specification.
Campbell

Amendment giving background and reference material.
Implies demarkation between V/STOL and airplane.
Koven

Delete definition of control power as technical function.
Write for flight test engineer. It's a designer's
rather than a demonstration manual.

V_{con} not specifically defined.
Craig

1.05 V_{stall} clean, AF suggestion - wing lift.
Campbell

Cooper scale should not be used in specification - Appendix. *Drinkwater*

Simultaneous use of controls - difficult - p.3 and p.27. No numbers for backing up a reduction. Maybe leave out Section 4.3 in Introduction.

Page 9, last sentence - Somewhere should have case of lift engines. *Lollard*

Page 8 - gradients for VTOL and not STOL - should be clarified. (Should be statement that those given are for VTOL régime). *Koven*

Page 7 - Table, collective friction up to four pounds. *Durand and Drinkwater*

Page 8, 1.3 - Suggested range for controls - not fixed specification.

Page 9, 3rd paragraph - Should change to desirable.
2nd paragraph - Spell out type of device.
Last 2 paragraphs - Belong? last one vague.

Page 11, Hovering ± wind velocity

Page 12, 2.4 - No instability for STOL permitted for 4th paragraph.

Page 12 - 3rd paragraph, F/g unrealistic - thought about.

Classes of aircraft instead of weight.
Thinks can put enough information together to separate. *Anderson*

M_u (speed stability) important (for consideration in control requirements). *Koven*

Roll due to dihedral in slip should be handled more adequately. *Merewether*

Roll and other response available for 35 knots around the clock. *A'Harrah and Drinkwater*

Let damping go. For IFR need to have some anyway. Can hover visually with very little damping. So for VFR or failure case no need to specify a damping. *Drinkwater*

Attitude systems need specifications. *Hafer*

Navy data shows damping requirements much higher in 5-10 second period range. *Koven*

Page 21 - Spiral stability, specify degree. *Craig*

Page 15 - Princeton ties spiral and Dutch roll stability together.

Page 27 - .5 should have failure case for vertical thrust response; i.e., engine-propeller combinations where lead network needed. *Koven*

Page 14 - $C_{l\alpha}$ effects different from airplane.

Page 16, 2.14 - 941 meets 0.9 $V_{T.O.}$, but not 10 knots. Five knots or 0.9 seems O.K.
May need to restrict early rotation.

Page 17 - 2.16 "Longitudinal control in combination with other controls (including power) as necessary."

Page 20, 3.5 - Point about designated wind conditions.

Page 21, 3.8 - Should include rate of divergence, 2^{o}/sec limit. Last paragraph say (failure case) 20^{o} or stay below fin stall. *Anderson*

Page 23, 3.12 - Roll response required too low. Pitch too high (Balzac).

Page 24, 3.14 - Could be 180^{o} turn. *Durand*

Page 25, 3.18 - Permit more rudder force for helicopters.

Page 26, 4.2 - Motion of height control should be specified as well as g/inch. Show curve?

Page 26, 4.2 - For suckdown effects, should require ± 1/2 inch and ± 2 ft/sec? Hafer says no.

Page 26, 4.3 - Should include precision of height control at same time.

Page 26, 4.3 - Define continuously - could be one minute for most cases.

Page 27, top - 50% all controls is too severe! Specify a reasonable maneuver and loss in altitude. Should be 50% of nominal control. Better definition of weights. *Hafer*

Page 27, 4.6 - Intake flow in all wind conditions.

Page 28, 5.1 - "power setting and tilt of thrust vector." Should be reworded. Too specific. *Durand*

Page 28, 5.4 - For STOL, need 1.2 from lift and propellers to flare at ground. With critical engine failure V_{mp} is raised.

5.4 - Does not handle lift engine case. Should be reworded to simpler statements.

5.2 - "stop, operate for short time steadily, and reverse."

5.5 - Maneuvering defined in terms of g .

5.7 - Should apply to a defined forward acceleration and deceleration.

6.1 - Should consider sinking speed? Feeling, no!

6.1 - Should include yawing motions.

6.2.1 - This should be failure case. Also should include time, for yawing case as example.

6.3 - Stringent. Take out! *Campbell and Drinkwater*

6.5.2 - Specify attitude change limits for multi-engine. Also, allow time interval of one second.

Page 34, 6.6.2 - Cover trim changes due to loss on control surface only. *Koven*

APPENDIX IV

Short Notes of Discussions on AGARD Report 408 by J.M.H. van Vlaenderen

(The writer did not attend the first morning session.)

2.12, 3.11, 3.12 <u>Response and Damping</u>

Control power should also be based on gust criteria. — *Koven*

Control sensitivity and damping from Tapscott's work is O.K. Control power extrapolated from total control movement - not reliable. Control power is more important design spec. Lower limits of control power well defined for visual flight, numbers buried in NASA report. — *Drinkwater*

Control power increase by washout of damping for large deflections possible (Balzac). How does this work out in flight? — *Lollard*

Princeton report on lower limit of control power from simulator studies. — *Koven*

Control power is for still air. Need for requirement for limiting wind? — *Drinkwater*

2.9, 3.9 <u>Dynamic Stability</u>

For conventional ILS longitudinal short-period oscillations in 5-15 sec range problem area. Increased damping required instead of less. — *Koven*

Discussion:
Might be result of g-response in conventional aircraft. VTOL different. In any case present recommendations probably oversimplification. — -

Spiral stability time to double amplitude 8 sec on ILS. Dutch roll damping requirement independent of frequency as long as Dutch roll is not divergent (not agreed by NASA). — *Koven*

2.6 <u>Time delay</u>. For height control first-order time constant (including time lag in control system) must be less than one second. — *Ames*

Vertically oscillating system is possible also (engine surge). — *Craig*

2.5 Initial negative g is not covered (delta aircraft). — *Lollard*

2.14 10 knot margin appears too high. 6 knot may be more appropriate (Breguet 941)

Premature lift-off with insufficient control power for flight should also be considered.

2.16 Power flare should be included.

3.1 Empahasize that sideslip is primarily caused by crosswind operation (35 knot) *Hawker*

3.8 Also adverse yaw rate. Suggest 2^o/sec maximum. For emergency case sideslip to be limited by fin stall (C-130 = 15^o, Breguet 941 = 20^o) *Ames*

3.10 Grumman report, 0.2 sec completely inadequate.

3.12 For visual flight, ratio of roll to pitch response 2.1. Roll response in 408 too low, pitch too high. *Hawker*

3.14 360^o turn for helicopters. For fighters 180^o adequate. *Durand*

3.18 Helicopter case from take-off power to autorotation not covered. Add helicopter requirement.

4.2 1/2 in based on helicopter. Suggest add g/inch for height control. *Craig*

Unnecessary to hover continuously in ground effect. *Hafer, Durand*

4.3 Precision of height control to be included. Is one minute sufficient to demonstrate "continuously"?

4.4 50% inputs for short duration only. Requirement too severe. Better weight definition required. *Hafer*

4.6 Any wind direction.

5.1 Controls named too specifically. Taken care of already by 5.3 *Durand*

5.4 Should be rewritten in simpler form. Military power in some configurations above structural limits. *Craig*

5.7 Maximum acceleration and deceleration should be stated. *Craig*

6.1 Landing conditions should be defined. Yawing motions must be included.

6.2.1 Grumman report on gyroscopic effects.
Yaw demonstration manoeuvre desirable. *McHugh*

6.3 Suggest to delete, because spin characteristics would have to be demonstrated. *Ames*

6.5.2 Define transient effects before regaining control. For example limit angles or altitude loss. Include pilot delay of 1 sec.

French proposal:

	A *Bail Out*	B *Emergency Landing*	C *Mission Accomplished*
Longitudinal	20^o in 3 sec	10% margin	20% margin
Lateral	20^o in 3 sec	25% margin	50% margin
Directional	20^o in 3 sec	25% margin	20% margin
Vertical	Depends on ejector seat characteristics	10 ft/sec touchdown	0

6.6.2 Trim change should be included.

APPENDIX V

Remarks on the Comments made by the Technical Assistance Panel

The following numbered comments refer to the same numbers in the Comments on AGARD Report 408 from the Technical Assistance Panel (pp.35-47).

1. (i) Yes.
   (ii) Yes.

2. Yes.

3. This is very desirable but it is not likely to be easily accomplished since a significant portion of the background is unpublished and simply represents the collective opinion of the Working Group.

4,5. The most significant omission with regard to helicopters is that pertaining to autorotation characteristics. This should be included. At this stage, helicopters provide the only broad operational experience available to form the basis of the requirements. If the VTOL aircraft must hover as a helicopter there is a good reason to feel it should be as maneuverable. I believe many of the reasons for this criticism come from a lack of knowledge of the significance of some of the fundamental response parameters, in particular those affecting the gust esponse. As more information becomes available from various investigations, the response and damping requirements can be rewritten to be more generally applicable.

6. I see no advantage in being more precise at this stage because the present document is meant to present design recommendations rather than requirements and data are not available to suggest a particular more precise definition of V_{con}.

7. No comment.

8,9,10. While differences exist between response and damping requirements for visual and instrument flight, they are not yet well defined. The present requirements were based primarily on the work reported in NASA TN D-58, where the experiments were conducted using a visual hovering and ILS approach task. I think the recommendations should be interpreted as applying to constant speed instrument approaches, with visual hovering and transition.

11. Yes.

12. Yes.

13. While it is possible to state an approximate root mean square gust intensity as a function of wind speed, the shape of the gust spectrum and correlation of lateral and vertical gusts may have a significant effect on the response. This is an area where investigations may lead to more rational response requirements, but the significant gust parameters are not as yet well defined.

14-17. Perhaps this statement should be stated that it is desirable as written, see, for example, the comment from AFFTC, Edwards Air Force Base.

18,19. I believe the present terminology is appropriate.

20. It is difficult to cover all the various SAS systems and this may be adequately covered under Section 4.1 where SAS failure is mentioned.

21-27. No comment.

28. It was agreed that flying the aircraft backwards at 35 to 40 knots is not realistic.

29. No comment.

30. This is indirectly covered for speeds below V_{PA} by 2.12 (response and damping) and 1.2 and 1.3 (control break-out and force gradients). At speeds above V_{PA} it was considered that stick force per g became more significant.

31. No comment.

32. Perhaps, but I doubt if many aircraft presently flying have a time delay much less than this if it is carefully measured.

33. It may be possible to accept longer delays for aircraft with direct fore-and-aft acceleration control, but some data are required before the limit can be suggested.

34. Recent tests at our establishment suggest the damping ratios specified do not appear adequate even for visual approaches. For example, our tests suggest the damping ratio should be about 0.4 for a 12-second period, but in general our results showed that the damping requirements were primarily related to the gust response. If the damping was sufficient to adequately reduce the gust response, the damping ratio of the oscillatory mode (directional) was much higher than that given by Figure 2.

35. No comment.

36-49. There is little doubt that the response and damping requirements need to be modified in the near future. The comments given in 36 to 49, however, are indicative of the wide range of opinions held on what is required, for example, Hawker claim that control sensitivity in hover is the overriding consideration, while Ames claim that control power is the significant parameter. In the light of the conflicting opinions, I believe the present recommendations are a reasonable compromise. I do not believe this question will be resolved without resort to investigations similar to the one we just completed where we demonstrated that N_v has a very strong effect on the required levels of damping and hence control power. The suggestion from these tests is that the aircraft's response to gusts is overriding in terms of the required damping, which in turn influences the required control sensitivity. Furthermore, while hovering in a wind, N_v has a direct effect on the control moment required to hover cross-wind and the margin required to adequately correct

for response to gusts. Similar effects are present that will have a strong influence on the required pitch and roll damping, as already demonstrated by tests at Princeton for the pitch responses. Parallel investigations are now in progress at Langley. I believe revision of the recommendations should be delayed until more comprehensive results are available from these various investigations. In the meantime, it might be well to point out the conflicting opinions, as well as the investigations now under way in an effort to establish more rational recommendations.

50. No comment.

51. I don't think the requirement as written precludes this.

52. Same as for VTOL operation.

53. L_v has a direct effect on the required lateral control power while hovering cross-wind, in much the same manner as the effect of N_v on the directional control power.

54,55. No comment.

56. Same comment as for 33.

57. 360° turn should apply to VTOL aircraft other than helicopters.

58. I believe this is an area where more work is required. The required margins are no doubt a function of the aircraft's gust sensitivity and until tests are conducted and analysed with this in mind it is difficult to establish reasonable criteria for margins.

59. No comment.

60. Yes.

61,62. No comment.

63. Covered in 4.2.

64. No comment.

65. Covered in 4.2. No opinion on failure case.

66. Meant to cover all VTOL aircraft.

67-70. It would appear that there has been considerable difficulty encountered in meeting this requirement and most evidence suggests it is too severe - particularly full control about one axis and 50% about the other two axes. A suggested recommendation is that the control applied about each axis be 3 times that required when the controls are applied to trim the aircraft in the most adverse condition in hover in the specified wind, the margin being required to manoeuvre and counteract gust disturbances.

71-79. No comment.

80,81. Agree with comments.

82,83. The present recommendation was based on flight tests at Langley with artificially induced gyroscopic coupling and I don't think they should be altered without more specific evidence.

84-88. No comment.